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OF THE

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SCIENCE HOUSE, GLOUCESTER AND ESSEX STREETS, SYDNEY

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Journal and Proceedings, Royal Society of New South Wales, Vol. 101, pp. 1–9, 1967

Organic Metals ? The Electrical Conductance of Organic Solids*

The Liversidge Lecture, Sydney, 1966

L. E. Lyons
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Introduction

This paper discusses electrical conduction in organic solids, leaving aside the spectral and photo phenomena in which I have been greatly interested for a number of years and omitting also the organic superconductivity recently discussed by Little (1964). Let us ask: How nearly can the electrical conductivity of an organic material be made to approach values typical of metals ?

This question at the moment is partly but not completely answered. Therefore I hope that the discussion tonight will encourage research in what in the last few years has become a very active front in the scientific advance; thus may I fulfil Archibald Liversidge's aim in establishing this lectureship, with the award of which the Royal Society of New South Wales has honoured me this year: my gratitude goes to Liversidge now just as it did when I entered the University of Sydney with a Liversidge scholarship.

Liversidge worked in the Department of Physiology in Cambridge University and of Chemistry in the University of Sydney, and was intimately concerned with the development of science as a whole; and the subject of electrical conduction in organic materials is related to chemistry and also to certain important aspects of physiology such as vision, as well as to solid state science to photosynthesis and to the mechanisms of some enzymic processes. The breadth of application of the subject of conduction in organic materials matches the extent of Liversidge's own scientific interests.

Professor Gutmann and colleagues (1966) have recently invented a new battery which uses organic solids, and yields 1·5 V, and is of potential use for space craft, being very light. No metal is necessary, Also, The General Electric Co. in U.S.A. have made a non-metallic wire. These results indicate that some extraordinary practical developments may arise from the studies we are discussing, but they are not the subject of this talk. A recent publication discusses all aspects of the subject [Gutmann and Lyons (1967)].

The Electrical Conductance of Metals and Inorganic Semiconductors

When there is but one type of charge carrier, an electron or a positive hole, the conductivity σ at a given temperature T and pressure p is given by the product of n, the number of carriers per cubic centimetre, and the mobility μ of the carriers:

$$\sigma = n\mu \qquad (1)$$

If μ is measured in cm^2 $volt^{-1}$ sec^{-1} then σ gives the number of electrons flowing per second in a field of 1 volt cm^{-1}. The significant but relatively minor differences between the Hall mobility and the drift mobility need not concern us in this discussion.

Table 1 summarizes some of the basic data on the electrical properties of metals and inorganic semi-conductors.

For metals, from Table 1, it is seen that

(i) n approximately equals the number of atoms cm^{-3};
(ii) σ drops as T increases;
(iii) μ drops as T increases; and
(iv) at room temperature, μ is often 10 to 100 cm^2 $volt^{-1}$ sec^{-1}.

For the inorganic semiconductor, Cu_2O

(i) n is much lower than the number of atoms cm^{-3};
(ii) σ and n both increase as T rises;
(iii) as in metals, $\mu \approx 10$ to 100 cm^2 $volt^{-1}$ sec^{-1}; and
(iv) as in metals, μ drops as T increases.

*Acknowledgement is gratefully made for financial support by a grant, Number AF-AFOSR-863-65, from the Directorate of Chemical Sciences, U.S.A.F. Office of Scientific Research, for work described herein.

TABLE 1
Data on Electrical Conductivity of Some Metals and Inorganic Semiconductors
(σ, conductivity ; μ, mobility ; n, concentration of carriers)

	T (°K)	σ (ohm^{-1} cm^{-1})	μ (cm^2 V^{-1} sec^{-1})	n (cm^{-3})	Number of Atoms (cm^{-3})
Ag	290	$6{\cdot}2\times10^{6}$	(—)50	$7{\cdot}7\times10^{22}$	$5{\cdot}9\times10^{22}$
Ag	15	$1{\cdot}1\times10^{9}$	(—)11,000	$6{\cdot}3\times10^{22}$	
Cu	290	$5{\cdot}8\times10^{6}$	(—)28	$13{\cdot}0\times10^{22}$	$8{\cdot}55\times10^{22}$
Na	293	$5{\cdot}8\times10^{6}$	(—)60	$2{\cdot}5\times10^{22}$	$2{\cdot}55\times10^{22}$
Zn	293	$1{\cdot}7\times10^{6}$	(+) 6	$19{\cdot}0\times10^{22}$	$6{\cdot}6\times10^{22}$
Ni	293	$1{\cdot}4\times10^{6}$	(—)90	$1{\cdot}0\times10^{22}$	$9{\cdot}1\times10^{22}$
graphite (in plane)		10^{5}	($\pm$)20,000	3×10^{18}	$1{\cdot}13\times10^{22}$
graphite (plane)		1	(+)		do
Cu_2O	163	$2{\cdot}0\times10^{-6}$	(—)200	$6{\cdot}3\times10^{9}$	$2{\cdot}5\times10^{22}$
Cu_2O	373	$9{\cdot}9\times10^{-2}$	(—) 20	$5{\cdot}6\times10^{11}$	
Ge (high purity)	300	2·4	(—)4,000	$3{\cdot}5\times10^{14}$	$4{\cdot}4\times10^{22}$
Ge (0·005Al)	100	140	(+)6,000	$1{\cdot}5\times10^{16}$	$4{\cdot}4\times10^{22}$
Ge (Sn)	100	83	(—)7,000	$7{\cdot}8\times10^{15}$	$4{\cdot}4\times10^{22}$

Source : Ehrenberg (1958).

For germanium semiconductors

(i) μ is much higher than μ in Cu_2O is in metals ;

(ii) n (and thus σ) can be determined by the concentration of an additive such as Al.

Conductivity of Organic Solids

(In this lecture the work of many workers is referred to ; the contribution of our research group has been to propose and test the general theoretical framework for organic conduction.)

The general result is typical of the behaviour of semiconductors

$$\sigma=\sigma_0 \exp(-E/2kT) \quad (2)$$

E is the thermal energy necessary to form carriers. When the carriers are generated thermally within the crystal and when μ is independent of temperature

$$\sigma_0=N\mu \quad (3)$$

where N is the concentration of centres capable of yielding carriers.

Measurements of σ_0 and of μ thus enable N to be deduced.

Mobility in organic crystals

The pulse method of Le Blanc (1960) and Kepler (1960) yields values of μ in anthracene and naphthalene which are all of the order of 1 cm^2 $volt^{-1}$ sec^{-1}. Positive holes and electrons differ slightly in mobility ; in either cases μ is anisotropic, as is shown in Table 2.

The mobility can be explained by band theory. Essentially a band of energy levels is formed for each molecular orbital, because of the overlap of the molecular orbitals in the crystal lattice. From the widths of the bands and from a theory of scattering the mobility can be calculated. On reasonable assumptions the results of theory agree with experiment.

TABLE 2
Experimentally Measured Values of Mobility in Anthracene and Naphthalene

	μ^+	μ^-
Anthracene		
Crystal ; $\perp$ (001)	0·4	0·3
	0·98$\pm$0·04	0·54$\pm$0·03
	0·43$\pm$0·05	
Crystal ; $\parallel$ (001)	1·3	2·0
Cast slab	0·48	
Crystal ; ? direction$\geq$	2·3	
Crystal	5×10^{-3}	
Crystal, $^a\mu_{aa}$	1·0	1·7
Crystal, $^a\mu_{bb}$	2·0	1·0
Crystal, $^a\mu_{c'c'}$	0·8	0·4
	$\mu^+/\mu^-=$	2·13
Crystal ; $\parallel$ (001)	0·8	0·4
Naphthalene		
Crystal, $^a\mu_{aa}$	0·9	0·7
Crystal, $^a\mu_{bb}$	1·4	0·7
Crystal, $^a\mu_{c'c'}$	0·4	0·4

$^a\mu_{aa}$ represents the component of the mobility tensor μ_{ij}, when $i=j=a$, where a is a crystal direction ; a, b, and c' are mutually perpendicular.

Source : Gutmann and Lyons (1967).

The " overlap " or " band " theory of mobility is supported by the observed decrease of μ with a rise in T, and by the observed increase of μ with a rise in p (Figs. 1 and 2), after Kepler (1962).

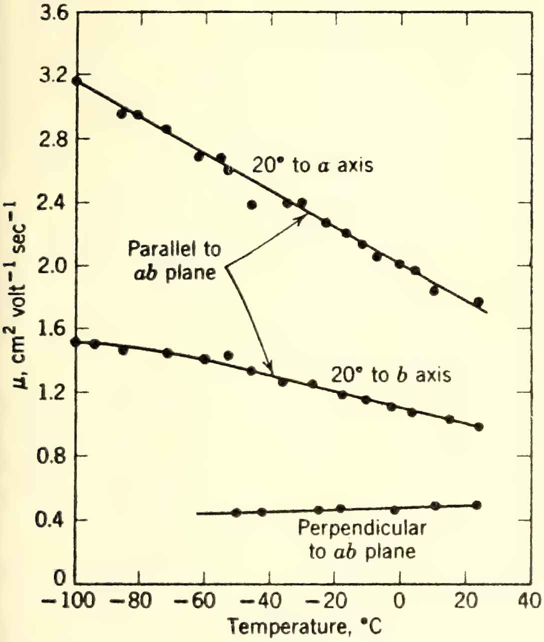

FIG. 1

Temperature dependence of electron mobility ; after Kepler (1962).

All values of μ might be expected to be of the same order of magnitude in a given class of crystal, e.g. in similarly structured molecular crystals of aromatic hydrocarbons.

Values of σ and of E are determined empirically from plots of log σ *vs* 1/T.

If $\mu \approx 1$ then σ_0 indicates the number of sources of carriers. Intrinsic conductivity would require σ_0 to be *ca.* 10^{21} cm^{-3}. Extrinsic conductivity would be undetectable if $\sigma_0 <$ *ca.* 10^9 cm^{-3}, unless E were very small.

Figure 3 summarizes the results of many workers on more than 160 substances. Nearly all lie within the expected limits for σ_0. The conductivity itself ranges over more than 20 orders of magnitude. In Figure 3, the lower on the diagram does a number (denoting a compound) occur, the greater is log σ ; and the more to the left does a number occur, the less is σ_0. Most observations of conductivity are therefore consistent with extrinsic rather than intrinsic mechanisms. The common occurrence of extrinsic mechanisms is consistent also with the known difficulty of obtaining hyper-pure organic compounds. None is yet available commercially in a grade comparable with that of the best germanium. From Figure 3 it is clear that less than one part in 10^{12} of an active impurity in many cases can affect the observed conductivity. A new technology of purification and operation is therefore called for. Many experiments should be done in the absence both of light and of oxygen.

The Energy Gap, E

In equation (2), E ranges from 0 to more than 3 eV. An explanation of E was given by Lyons (1957). For intrinsic conductivity thermal generation of carriers requires an energy given by equation (4).

$$E = I_c - A_c \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

where I_c and A_c are the energies of subtracting and of adding an electron to the crystal.

Values of I_c can be obtained by photoemission experiments. I_c can also be related to the molecular ionization energy I_G by the polarization energy P, through equation (5) ;

$$I_G = I_c + P \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

We have established that I_c is less than I_G, usually by about 2 eV. Values of $I_G - I_c$ (=P) are shown in Table 3.

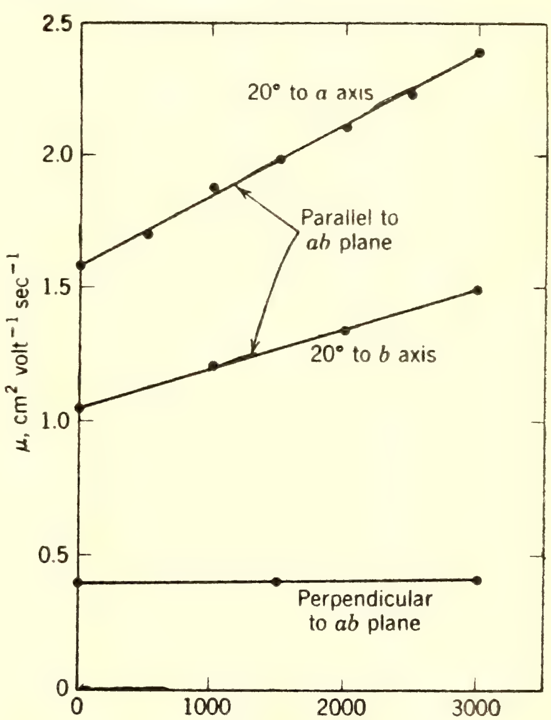

FIG. 2

Pressure dependence of electron mobility ; after Kepler (1962).

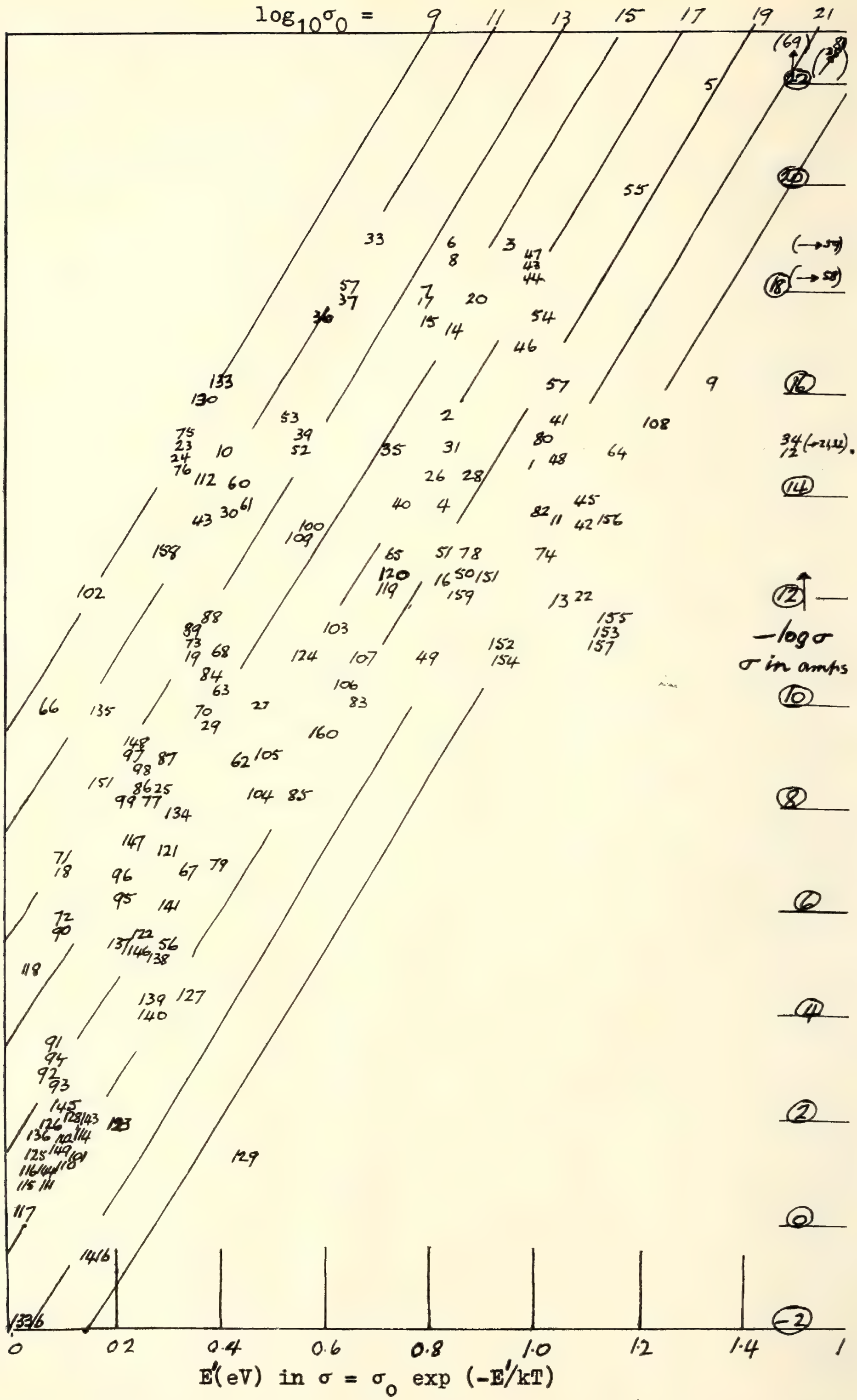

FIG. 3

Values of σ_0 for observed E and σ in reported experiments on dark conductance. (σ_0 is in amps $\times 10^{19}$)

Calculation of P was made from the formula

$$P=\sum_{k<1} \alpha^2 e^2 r_k^{-3} r_l^{-3} r_k^{-3}[\boldsymbol{r}_k \cdot \boldsymbol{r}_l - 3r_{kl}^{-2}(\boldsymbol{r}_k \cdot \boldsymbol{r}_{kl})(\boldsymbol{r}_l \cdot \boldsymbol{r}_{kl})] - \sum_{1}^{N-1}{}_k e^2\alpha/r_k^4$$

More complicated expressions involving higher terms and anisotropic molecular polarizabilities are given by Mackie (1964) and by Batley (1966) who used also a computer programme to increase the accuracy. The theory assumes (i) crystal structures from x-ray work and (ii) molecular polarizabilities, available in many instances from the work of Professor Le Fèvre and colleagues. [Le Fèvre and Sundaram (1963)].

TABLE 3

Values (eV) of I_G–I_c Equated to the Polarization Energy P of a Single Charge

Anthracene	1·8	Perylene	1·9
Chrysene	2·1	Phenanthrene	1·4
Coronene	2·4	Phthalocyanine, Zn	1
9, 10-Dibromo-anthracene	1·9 to 2·4	Pinacyanol	2·3
		Pyrene	1·7
n-Hexane	1·7	Quinoline blue	2·0
Indigo blue	1·8	Rhodamine 6G	1·6
Merocyanine	2·2	Water	5·6 to 7·0
Naphthacene	1·6		
Naphthalene	1·3		

Source : Gutmann and Lyons (1967).

When account is taken both of ion induced-dipole and dipole-dipole interaction the theory calculates P to lie within a few tenths of an electron volt of the observed difference between I_G and I_C. Since there are errors in experiments and necessary approximations in the theory, the agreement is satisfactory. In this way the theory of photoelectric emission thresholds in organic solids has been established reasonably well. Calculated values are shown in Table 4. The *electron affinities* A_C of certain dye crystals have been reported as $3{\cdot}3 \pm 0{\cdot}3$ eV (Nelson, 1956). There is no other direct measurement. However, A_C can be related to the corresponding molecular property A_G by equation (6).

$$A_G = A_C - P \quad \ldots\ldots\ldots\ldots\ldots \quad (6)$$

where P refers to the energy of the polarization produced by the negative charge, a quantity which will be very close to that produced by a positive charge.

Key to Fig. 3 : 1–5, anthracene ; 6–7, anthanthrene ; 8, anthanthrone ; 9, benzanthrone ; 10, benzene ; 11, benzimidazole ; 12, o-chloranil ; 13, chlorpromazine ; 14–17, coronene ; 18, cyananthrone ; 19, flavanthrone ; 20, hexamethylbenzene ; 21, hydroviolanthrene ; 22, imidazole ; 23, indanthrazine ; 24, indanthrone ; 25, indanthrone black ; 26–27, 30, isoviolanthrene ; 28–29, isoviolanthrone ; 31, naphthacene ; 32–35, naphthalene ; 36, m-naphthodianthrene ; 37, m-naphthodianthrone ; 38, octohydroviolanthrene ; 39, ovalene ; 40, pentacene ; 41–47, perylene ; 48, phenazine ; 49, phenothiazine ; 50–51, phthalocyanine ; 52, pyranthrene ; 53, pyranthrone ; 54–55, pyrene ; 56, quaterrylene ; 57, α-resorcin ; 58–59, β-resorcin ; 60–63, violanthrene ; 64, Banfield and Kenyon's radical ; 65, Coppinger's radical ; 66, DPPH ; 67–68, violanthrone-B compound ; 69, 1,9,4,10-anthradipyrimidine ; 70, crystal violet ; 71–72, cyananthrone ; 73, flavanthrone ; 74, fluorescein-Na ; 75, indanthrazine ; 76, indanthrone ; 77, indanthrone black ; 78, indigo ; 79, nacrosol black ; 80, orthochrome T ; 81, 5,6-(N)-pyridino-1,9-benzanthrone ; 82, acenaphthene : TCNE ; 83, anthracene : TCNE ; 84, azulene : TCNE ; 85, β-carotene triiodide ; 86, coronene : iodine ; 87–89, 1,5-diaminonaphthalene : chloranil ; 90–91, 1,6-diaminopyrene : chloranil ; 92–93, 3,8-diaminopyrene : bromanil ; 94, 3,8-diaminopyrene : chloranil ; 95, 3,8-diaminopyrene : iodanil ; 96, 3,10-diaminopyrene : chloranil ; 97, dimethylaniline : bromanil ; 98, dimethylaniline : chloranil ; 99, dimethylaniline : iodanil ; 100, hexamethylbenzene : TCNE ; 101, isoviolanthrene : $(AlCl_3)_{3\cdot2}$; 102, isoviolanthrone : $(AlCl_3)_{3\cdot7}$; 103, isoviolanthrone : $(ICl)_{1\cdot45}$; 104, isoviolanthrone : $(ICl)_{1\cdot90}$; 105, isoviolanthrone : $(ICl)_{3\cdot73}$; 106, isoviolanthrone : $(TiCl_4)_{1\cdot87}$; 107, lithium : anthracene ; 108, naphthalene : TCNE ; 109, pentamethylbenzene : TCNE ; 110, perylene : $SbCl_5$; 111, perylene : Br_2 ; 112, perylene : chloranil ; 113, perylene : fluoranil ; 114–117, perylene : iodine ; 118, perylene : metal halides ; 119, perylene : TCNE ; 120, phenanthrene : TCNE ; 121, phenylenediamine : chloranil ; 122, p-phenylenediamine : chloranil ; 123, phthalocyanine : chloranil ; 124, potassium : anthracene ; 125–126, potassium : isoviolanthrene ; 127, potassium : TCNQ ; 128, pyranthrene : bromine ; 129, pyranthrene : iodine ; 130, pyrene : chloranil ; 131, pyrene : iodine ; 132, pyrene : TCNE ; 133, pyrene : TCNQ ; 133*b*, quinolinium : $(TCNQ)_2$; 134, Na : anthracene ; 135, Na : 3,4-benzoquinoline ; 136, Na : isoviolanthrene ; 137, Na : isoviolanthrene ; 138, tetramethyl-p-phenylenediamine : bromanil ; 139–140, tetramethyl-p-phenylenediamine : chloranil ; 141, tetramethyl-p-phenylenediamine : iodanil ; 141*b*, triethylammonium $(TCNQ)_2$; 142, violanthrene : Br_2 ; 143–148, violanthrene (V) : I_2, mole ratio (V : I_2), 1 : 3·7, 1 : 1·9, 1 : 0·118, 1 : 0·01, 1 : 0·0036, 1 : 5×10^{-4} ; 149–150, V : I_2 ; 151, V : TCNE ; 152, dipyrromethene-1, cobalt ; 153, dipyrromethene-2, cobalt ; 154, dipyrromethene-1, copper ; 155, dipyrromethene-2, copper ; 156, dipyrromethene-1, hydrobromide ; 157, dipyrromethene-2, nickel ; 158, ferrocene ; 159, phthalocyanine, Cu ; 160, phthalocyanine, Mg ; 161, phthalocyanine, Zn.

Source of data : Gutmann and Lyons (1967)

Thus if we can get A_G we can determine A_c and *vice versa*. In the course of our work we have used two methods of arriving at values of A_G. The first general method derived A_G from polarographic reduction potentials in solution [Lyons (1950)], while the second derived A_G from charge-transfer spectra in solution [Briegleb (1961), Batley and Lyons (1962)]. In addition theoretical and other methods of various kinds have been used [e.g. Hoyland and Goodman (1962)].

TABLE 4

Calculated Values of Polarization Energy (eV)

	P_I Ion-dipole	P_D Dipole-dipole	P_I+P_D
naphthalene	—2·01	+0·41	—1·60
anthracene	—2·35	+0·54	—1·81
naphthacene	—2·81	+0·66	—2·15
pentacene	—2·08*	+0·64	—1·44*
coronene	—2·21*	+0·37	—1·84*
chrysene	—2·30*	+0·82	—1·48*
anthracene : TNB	—2·53*	+0·37	—2·16*

* Ion-dipole term not extrapolated to infinite radius.

All methods suffer from the difficulty of how to place the values on an absolute scale. However, when values relative to benzene are considered, the various methods yield values in reasonably good agreement with each other as Table 5 shows. [For absolute values, the discrepancies amongst the results of various methods have very recently been removed by Batley (1966).]

Thus, whilst relative molecular electron affinities are available at least for the aromatic hydrocarbons the lack of an accurate absolute value is still a problem in understanding the electrical properties of solids. This appears when equation (4) is rewritten using equations (5) and (6), as

$$E=I_G—A_G—2P \quad \ldots\ldots\ldots\ldots \quad (7)$$

The validity of this approach is seen in the case of dyes which in Figure 3 were found to obey the equation for intrinsic conductivity. Also A_C ($=A_G+P$)$=3\cdot3$ eV typically [Nelson (1956)] and I_C ($=I_G—P$)$=5\cdot1$ eV typically. We thus predict E as $5\cdot1—3\cdot3=1\cdot8$ eV (eq. 4), a value which compares with the typical experimental value of 1·8 eV (Figure 3). The general mechanism is thus supported. Incidentally also, the molecular electron affinity of the dye molecule can be deduced to be 1 eV, because

$$A_G=A_C—I_G+I_C \quad \ldots\ldots\ldots\ldots \quad (8)$$

There is a further set of experiments to which the same basic theoretical approach can be applied: *The effect of high pressure* upon the electrical conductivity of organic substances was observed but was unexplained until recently. It had been shown (Harada *et al.* 1964) that the greatly increased conductivity which is observed at high pressure is only 10% explicable in terms of an increased mobility. The increase in σ must therefore be caused by an increase in the number of carriers i.e. by a decreased value of E. We now use equation (7) to discuss the decrease in E.

The polarization energy, calculated as described above, is a function of the lattice parameters and must change when the crystal is compressed. Batley and Lyons (1966) have shown that the increase in carrier concentration can be explained by the change in the size of the unit cell with pressure (see Figure 4). Using the equation

$$kT\ln\left[\frac{\sigma_p}{\sigma_{o,\,p}}\cdot\frac{\sigma_o}{\sigma}\right]=\Delta P \quad \ldots \quad (9)$$

where the subscript p denotes values at high

TABLE 5

Electron Affinity Energies ΔA_G of Organic Molecules Relative to that of Benzene

Substance	ΔA_G	Mean
Anthracene	1·8	2·0
	1·8	
	2·0	
	2·1	
	2·0	
	2·1	
Coronene	1·8	1·85
	1·9	
	1·8	
Diphenyl	1·1	
	0·8	
	1·3	
Naphthacene	2·4	2·3
	2·4	
	2·2	
Naphthalene	1·1	1·2
	1·0	
	1·3	
	1·2	
	1·3	
	1·4	
Perylene	2·1	2·2
	2·3	
	2·2	
Phenanthrene	1·4	1·4
	1·6	
	1·6	
	1·1	
Pyrene	1·6	1·9
	1·7	
	2·3	
	2·0	

Source: Gutmann and Lyons (1967).

pressure and $\Delta P = P_p - P$ the theory in fact rather over explains the observations, which however are at present subject to an unknown error. Because

$$E_p = E - 2\Delta P \quad \ldots\ldots\ldots\ldots \quad (10)$$

an interesting situation is predicted to arise when ΔP is sufficient to make E_p equal to zero. In this case equations (2) and (3) yield

$$\sigma = N\mu \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (11)$$

so that $\sigma \approx 10^3$ to 10^4 ohm^{-1} cm^{-1}, a value which approaches that of metals. This behaviour has been observed, e.g. in copper and metal-free phthalocyanine. On returning to atmospheric pressure the metallic behaviour disappears, again as the theory predicts.

TABLE 6

Molecular Ionization Energy, I_G, and Molecular Structure

	I_G (eV)	Substituted benzene	I_G (eV)
benzene	9·245	—H	9·245
naphthalene	8·12	—CH_3	8·81
anthracene	7·38	—C_2H_5	8·76
naphthacene	6·88	—CHO	9·45
		—$COCH_3$	9·65
		—CN	9·705
		—NH_2	7·56
pyridine	9·32	—$NH.NH_2$	7·64
p-benzoquinone	9·67	—OH	8·52
phenothiazine	7·14	—SH	8·33
1,5-naphthalene diamine	7·2	—φ	8·27
bis-cyclopentadienyl Co	6·2	—NH_2, —NH_2 } para	7·2
		—$N.Ne_2$, —$N.Ne_2$ }	6·8

Source: Gutmann and Lyons (1967).

Conductivities at p = 1 bar

Using equation (7), and requiring E to be low, it is clear that in order to increase σ we must (i) decrease I_G, (ii) increase A_G, and/or (iii) increase P. Since P varies only over a limited range we consider only I_G and A_G in this section. The dependence of I_G upon molecular structure is shown in Table 6 which presents only a sample of values. For example, I_G is lowered (i) by an increase in conjugation and (ii) by the introduction of $-N.Me_2$, $-NH_2$, –OH, and $-CH_3$ groups.

The dependence of A_G upon molecular structure is such that A_G increases (i) with an increase in conjugation and (ii) with the introduction, e.g., of –CN, $-NO_2$, or –Cl substituents.

For crystals containing only one type of molecule conduction is favoured if there is extensive conjugation. Graphite is a limiting case here: its properties are wellknown (*cf.*

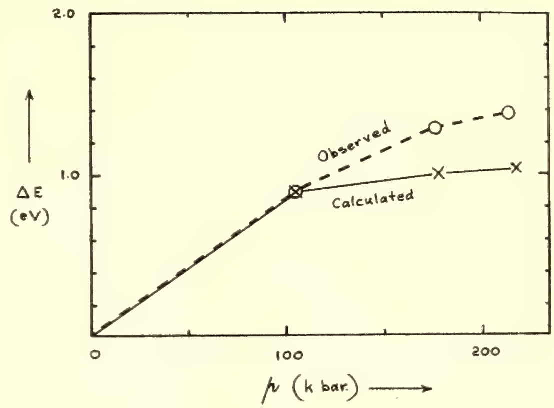

FIG. 4

Change ΔE of the energy gap with pressure, p, for the semiconductivity of pentacene. Batley (1966).

Table 1). Pohl and colleagues [Pohl (1962)], as well as other workers, have made scores of polymers in which conjugation extends throughout the polymer molecule. As expected I_G is low, A_G is high and so σ is high: $\sigma = 10^{-3}$ for poly dibenzpyrene (E = 0·2eV); and $\sigma = 10^{-4}$ for polypyrene (E = 0·2eV). The lack of a perfect single crystal lowers μ to 10^{-2} or 10^{-3} cm^2 volt^{-1} sec^{-1} and so limits σ.

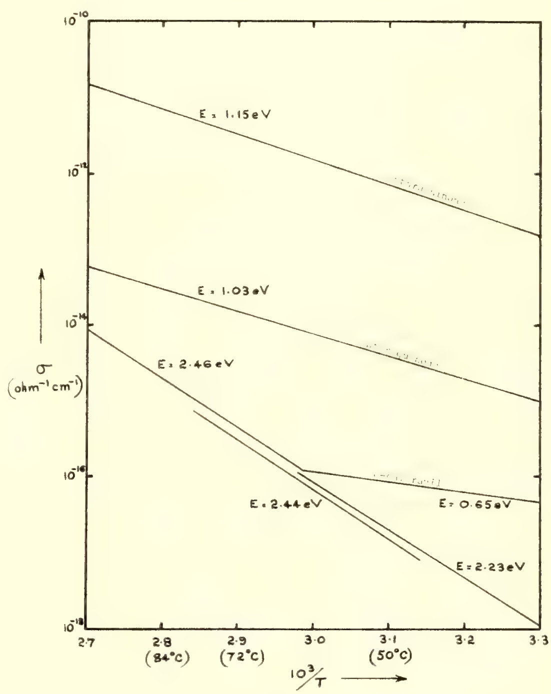

FIG. 5

Conductivity *vs* inverse temperature plots for anthracene crystal containing additives. Johnston and Lyons (1966).

Polyacenequinone radicals polymers can show $\sigma=10^{-5}$ ohm, with μ probably about 10^{-2}, and $E\geq 0 \cdot 26$eV.

TABLE 7

	E_{imp}	A_G (est)	$E_{imp}+A_G$
o-chloranil	0·65	1·9	2·55
pentacene	0·95	1·2	2·1
anthraquinone	1·10	1·05	2·1
anthanthrene	1·12	?	
tetracene	1·23	0·95	2·2
perylene	1·6	0·9	2·5

Source: Johnston and Lyons (1966).

Doping

The addition to a crystal of a small amount of an additive which has a lower I_G or a higher A_G than the corresponding value for the host molecule should lower E and raise the conductivity. Figure 5 shows that this is in fact so. Table 7 indicates that it is A_G rather than I_G which is important here. The E values decrease as A_G is increased. Once again support is obtained for the usefulness of equation (7).

Doping with an alkali metal ($I_G \approx 5$eV) is expected to give similarly increased conductivities. Amongst organic materials bis-cyclopentadienyl cobalt ($I_G=6 \cdot 2$eV) should be worth trying and this we plan to do.

The limiting case of "doping" is found in the *donor : acceptor complexes* which can be, e.g., 1 : 1 or 1 : 2. Table 8 lists the resistivities

TABLE 8
Electrical Resistivities of Some Donor Acceptor Complece

Donor	Acceptor	Mole Ratio	Resistivity Ohm Cm
acenaphthene	TCNE		5×10^{13}
benzidine	I_2	1 : 1	10^6
caesium	tetrachloss pyrene		8
3,8-diaminopyrene	domanil		10^3
perylene	domanil		8
perylene	iodine	2 : 3	3

Source: Gutmann and Lyons (1967).

of some donor acceptor complexes. Of those listed the lowest resistivity is that of perylene-iodine. For the 1 : 3 complex $\rho=8$ ohm cm, while for the 2 : 3 complex $\rho=3$ ohm cm, with $\mu<0 \cdot 01$.

Some 1 : 1 donor complexes, such as K^+ chloranil$^-$, are completely ionic and there is a resemblance to K^+Cl^- type solids. Using I_G and A_G values Mackie (1964) predicted the existence of a number of such substances. However, the resistivity is high—potassium chloride is an insulator.

For good conductivity it is necessary not only to have an abundance of ions such as chloranil$^-$ but also to have neutral molecules as neighbours to the ions. The electron can then move from one site to its neighbour with practically no change in energy. Steric arrangements should be suitable for the electron transfer. A favourable arrangement has been found amongst 1 : 2 complexes. Thus the conductivity of K^+ $TCNQ^-$ is *ca.* 10^{-4} ohm^{-1} cm^{-1}, while that of K^+ $(TCNQ)^-_2$ is *ca.* 10^{-2}.

Similar and even higher conductivities can be obtained with completely organic materials, e.g. for NEt^+_4 $(TCNQ)^-_2$, $\sigma\approx7$; and for Q^+ $(TCNQ)^-_2$, $\sigma\approx100$; where Q^+ denotes the quinolinium ion; Et, the C_2H_5 group; TCNQ, tetracyanoquinodiemethane.

TABLE 9

Crystal	Number of Molecules cm^{-3}
anthracene	$4 \cdot 3\times10^{21}$
naphthacene	$3 \cdot 5\times10^{21}$
naphthalene	$5 \cdot 4\times10^{21}$
perylene	$3 \cdot 3\times10^{21}$

In Q^+ $(TCNQ)^-_2$ the mobility in pellets is rather small (10^{-2}). No good independent measurement of the mobility on single crystals exists. Such measurements would allow a study of the possibility that μ has been limited by impurities and other crystal defects. If this is so and μ could be increased by better purification of the crystals then σ would be raised to perhaps 10^4 ohm^{-1} cm^{-1}.

Ultimate Limits on High Conductivity of Organics

Table 9 gives the number of molecules in a centimetre cube of some aromatic hydrocarbons. These values are all slightly more than one order of magnitude less than those found with metals. The simple fact that an organic molecule is bigger than a metal atom means that the number of sources for carriers must generally be less than in metals.

None the less conductivities as great as those in metals are not inconceivable. What is lost in the number of carriers may possibly be offset in the mobility. Although mobilities in the anthracene type crystals so far measured are relatively low, there are already a few

experiments which point to higher mobilities in favourable directions in certain crystals. Conjugated polymers as single crystals and some hydrogen-bonded crystals are likely examples. It must be remembered that in graphite $\mu \approx 20{,}000$ cm^2 V^{-1} sec^{-1}.

Conclusion

The day may well arrive when organic materials other then graphite will be made with conductivities of 10^4 or greater. Speaking electrically, organic metals exist already at high pressures, and the theory outlined in this paper shows that at present they are not far from existing under ordinary pressures.

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Abiogenesis Leading to Biopoesis

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Introduction

As protein is the basic building material of all the living system of our earth, the abiogenesis of protein is one of the most important aspects of biopoesis. However protein formation starts with the search for the process under which the amino acids are formed abiogenically. Several processes have been discovered which form amino acids under abiogenic conditions. The formation of amino acids was observed for the first time by Loeb in 1913[1] who reported the formation of amino acids as glycine and alanine by passing silent electric discharge in a mixture of formaldehyde, ammonia and water. Amino acids have been synthesised by passing electric discharge in a mixture of gases by Miller[2]. The photochemical formation of natural amino acids was observed by Bahadur[3, 4, 5], in sterilised aqueous mixtures containing organic substances and inorganic catalysts. Hasselstrom exposed aqueous solution of ammonium acetate and observed the formation glycine and aspartic acid[6]. The synthesis of amino acids and other compounds of biological interest have been done using isocyanates[7], energy from ultra violet rays[8] to x-rays radiations[9] and other sources of energies have also been used for this abiogenesis.

The next important step in abiogenesis was the formation of peptide linkage. Fox[10] synthesised peptides by heating the mixtures of amino acids to 180°C for a few hours. Akabori[11] synthesised peptide by exposing aqueous mixture of amino acids to ultra-violet light. Terenin[12] suggested the possibility of effecting the reactions needing quanta of large amount of energy by radiations of shorter quanta of energy if the substrate molecules are absorbed on solid substances. Bernal[13] reported the formation of peptides by the radiations available on the earth in the mud. Bahadur and Ranganayaki in 1958 observed the formation of peptides in aqueous mixture of amino acids containing colloids of iron and molybdenum oxides as catalysts on irradiation with sunlight or artificial light from an electric bulb[14]. Perti and Pathak[15] observed the formation of peptides in aqueous mixtures using visible light and ultra-violet light in presence of inorganic catalysts. Briggs confirmed the observation of photochemical formation of peptides[16]. The synthesis of peptides in aqueous mixtures using hydrogen cyanide as the dehydrating agent has been observed by Lowe[17].

The photochemical formation of peptides in aqueous mixtures is interesting and becomes important because, put together with the observation of photochemical formation of amino acids, it is quite probable that amino acids were first formed in the oceans of the primitive earth and then these were subsequently utilized for the formation of peptides in almost the same environment or on prolonged exposure. These photochemically formed peptides have been examined for enzymic activity. The results show enzymic function as phosphatase activity.

Bahadur[18] suggested that the formation of amino acids and peptides took place in aqueous environment in the prebiological era and solar radiation and visible light played an important role in the syntheses. Then on further molecular evolution proteins were formed. This theory regarding the origin of life on the earth has been developed recently[19, 20].

In the present communication an attempt has been made to study the formation of amino acids, peptides, organic acids, sugars and enzyme activity in sterilised aqueous mixture containing glycine, methionine, aspartic acid cystein and anthracene as catalysts by exposing these mixtures to artificial light.

Experimental

A set of two mixtures in sigcol flat bottom flask of 250 ml. capacity was prepared in glass distilled water. The contents of the mixtures were as follows :

Glycine ..	..0·05 gm.
Aspartic acid	..0·05 gm.
Methionine	..0·05 gm.
Cystein HCl	..0·05 gm.

and Anthracene 0·02 gm. as catalyst in 100 ml. of water.

TABLE 1

Mixture of Uncovered Flask (Light)

S.No.	Rf Values in Phenol : Water 80 : 20	Rf Values in Butanol : Acetic acid : Water 120 : 30 : 50	Identification	Remark
Microstructures :				
Hydrolysed	0·16	0·14	Cystein	Yellow
	0·15	0·28	Aspartic acid	Pinkish purple
	0·32	0·26	Serine	Purple
	0·52	0·27	Arginine	Purple
	0·58	0·34	Alanine	Purple
Unhydrolysed	0·51	0·27	Arginine	Purple
	0·61	0·81	Peptide	Purple
	0·31	0·71	Peptide	Purple faint
	0·28	0·69	Peptide	Purple faint
Environmental Medium :				
Unhydrolysed	0·16	0·14	Cystein	Yellow
	0·75	0·58	Peptide	Purple
	0·52	0·59	Peptide	Purple
Hydrolysed	0·16	0·14	Cystein	Yellow
	0·15	0·28	Aspartic acid	Purple (pinkish)
	0·30	0·35	Glutamic acid	Purple
	0·52	0·27	Arginine	Purple
	0·41	0·31	Glycine	Purple
	0·81	0·70	Methionine	Purple
	0·61	0·52	?	Purple

The flasks containing above mixtures were cotton plugged with surgical cotton, and sterilised at 15 lbs. pressure for 30 minutes in an autoclave. The mouth of the flasks was sealed with cello-adhesive tape after wrapping with polythene paper. One of the two fllasks was covered with thick black cloth and the other remained as such. The covered and uncovered flask was kept for exposure to artificial light under 1000 watt electric bulb. The temperature during the period of exposure varied from 18° to 30°C. After 560 hours of irradiation to artificial light, the mixtures of covered and uncovered flask were examined under the oil immersion microscope (D. R. P. Leitz wetzlar microscope) using aseptic conditions and no bacterial growth was observed. The sterility of the exposed mixtures was also checked by the culture-count method. Few drops of the exposed mixtures to be tested were introduced over the agar nutrient in the petridishes under aseptic conditions and kept at 35° in the incubator for three to four days. The mixtures did not show any bacterial growth during the exposure. These mixtures were analysed for their microstructures and environmental medium after separating them by the help of ultra centrifuge, each was analysed for hydrolysed and non-hydrolysed nitrogenous constituents by two way paper chromatographic technique, employing phenol-water (80 : 20) and butanol—acetic acid-water (120 : 30 : 50) as two running solvents. Hydrolysis was done with 10N—HCl in sealed, hard neutral glass ampules, kept in boiling water for 24 hours. The hydrolysed samples were dried and neutralised simultaneously in vacuum desiccator in presence of fused NaOH. Whatmann No. 1 chromatographic papers were used. Spots of amino acids and peptides were developed by spraying 0·2% ninhydrin solution in acetone over the dried chromatograms, spots of organic acids by 1% bromophenol blue. Spots of sugars were developed by ammoniacal silver nitrate. The Rf values change due to many factors such as change of solvent and also due to the degree of hydration of the same solvent.

TABLE 2

Mixture of Uncovered Flask (Dark)

S.No.	Rf Values in Phenol : Water 80 : 20	Rf Values in Butanol : Acetic acid : Water 120 : 30 : 50	Identification With 0·2% ninhydrin in acetone	Remark
Microstructures :				
Unhydrolysed	0·16	0·14	Cystein	Yellow
	0·18	0·21	Peptide	Purple
	0·43	0·35	Peptide	Purple
Hydrolysed	0·15	0·28	Aspartic acid	Pinkish purple
	0·81	0·70	Methionine	Purple
	0·16	0·14	Cystein	Yellow
	0·41	0·31	Glycine	Purple
	0·51	0·27	Arginine	Purple
	0·56	0·73	?	Purple
Environmental Medium :				
Unhydrolysed	0·16	0·14	Cystein	Yellow
	0·15	0·28	Aspartic acid	Pinkish purple
	0·31	0·39	Aleptide	Purple
Hydrolysed	0·16	0·14	Cystein	Yellow
	0·15	0·28	Aspartic acid	Pinkish purple
	0·81	0·69	Methionine	Purple
	0·41	0·31	Alycine	Purple
	0·51	0·27	Arginine	Purple

Therefore the Rf values of known, amino acids, organic acids and sugars were occasionally determined and the Rf values of unknown amino acids, acids and sugars were compared with those of known ones. The two running solvents were used in all the experiments for identification. This was accompanied by two dimensional chromatography.

TABLE 3

Mixture of Uncovered Flask (Light)

S.No.	Rf Values in Phenol : Water 80 : 20	Rf Values in Butanol : Acetic acid : H_2O 120 : 30 : 50	Identification With 0·2% Bromophenol Blue	Remark
Microstructures :				
Unhydrolysed	No spot	No spot	—	—
Hydrolysed	0·51	0·42	?	Yellowish
	0·32	0·21	Benzoic acid	Yellowish
Environmental Medium :				
Unhydrolysed	0·32	0·21	Benzoic acid	Yellow
	0·51	0·42	?	Yellow
	0·24	0·21	?	Yellow
Hydrolysed	0·78	0·62	Myristic acid	Yellow
	0·36	0·83	Oxalic acid	Yellow
	0·24	0·24	?	Yellow

Estimation of phosphatase activity :

The phosphatase activity was estimated colorimetrically employing the Klett Summerson photo-electric colorimeter for the measurement of intensity of colour produced using suitable filter. The analysis is based upon the measurement of the quantity of light absorbed by a coloured solution. The dilution of the solution was adjusted so as to hold Beer's Law, i.e. the scale reading was directly proportional to the concentration of phosphate ions in the mixture. To avoid the frequent change in potential of the current supply the voltage stabiliser was used.

The results of the chromatographic analysis of each flask are recorded in tables 1 to 7.

One more identical mixture, as described in the experimental portion of this paper, was prepared. It was sterilised, cooled, covered with four folds of thick black cloth and stored in a lead chamber the walls of which were made

TABLE 4

Mixture of Covered Flask (Dark)

S.No.	Rf Values in Phenol : Water 80 : 20	Rf Values in Butanol : Acetic acid : H_2O 120 : 30 : 50	Identification With 0·2% Bromophenol Blue	Remark
Microstructures :				
Unhydrolysed	No spot	No spot	—	—
Hydrolysed	0·32	0·21	Benzoic acid	Yellow
	0·38	0·35	?	Yellow
Environmental Medium :				
Unhydrolysed	0·32	0·21	Benzoic acid	Yellow
	0·14	0·40	?	Yellow
Hydrolysed	0·36	0·83	Oxalic acid	Yellow
	0·78	0·62	Myristic acid	Yellow

of 2·54 cm. thick sheets of solid lead. This mixture was analysed at the end of the experiment and was found to contain only the added amino acids. No other spot of amino acids, peptide, sugar or organic acid was detected in this mixture. There was no appearance of any microstructures in this mixture and the mixture had no phosphatase activity. Thus this control remained unchanged during the period of experiment.

TABLE 5

Mixture of Uncovered Flask (Light)

S.No.	Rf Values in Phenol : H_2O	Rf Values in Butanol : Acetic acid : H_2O	Identification With Ammoniacal Silver Nitrate	Remark
Microstructures :				
Unhydrolysed	0·53	0·31	Mannose	White
	0·24	0·52	?	White
	0·56	0·22	Sucrose	White
Hydrolysed	0·53	0·31	Mannose	White
	0·52	0·28	Glucose	White
	0·26	0·50	?	White
Environmental Medium :				
Unhydrolysed	0·53	0·31	Mannose	White
	0·26	0·52	?	White
Hydrolysed	0·53	0·31	Mannose	White
	0·52	0·28	Glucose	White
	0·36	0·56	?	White

Discussion

The chromatographic analysis of irradiated aqueous mixtures containing glycine, aspartic acid, methionine, and cystein and anthracene as catalyst indicated the presence of original amino acids added in the mixture together with a few peptide spots. This mixture on hydrolysis showed the presence of all the original amino acids and also gave newer spots which were identified as, arginine, alanine, and seriene. Similar mixture kept in dark showed the presence of all the originally added amino acids together with a few peptide spots. The mixture on hydrolysis gave the spots of the added amino acids and also of arginine, alanine and seriene as in exposed mixture. In general it has been observed that there were a few spots in unhydrolysed samples, but the same sample on hydrolysis indicated several spots which revealed the constituent amino acid of those peptides which did not appear over the chromatogram of the unhydrolysed sample. The complete identical mixtures kept in dark furnished peptide spots but these were lesser in number than those of the exposed mixture. It has been observed by Bahadur and co-worker[19] in their studies of the photochemical formation of amino acids and peptides that the control identical mixtures kept in dark also show some amino acids and peptide synthesis. They further observed that similar mixtures kept in lead chamber remained unchanged. The fact is that radiations which penetrated through the thick black cloth and reached the mixture kept in dark were also effective in the synthesis of some of these products. In the above lead chamber which had one inch thick wall of solid lead, all the radiations including cosmic radiations were cut off and no change in the mixture was effected. Microstructures were observed in the mixtures after exposure. Similar micro structures but lesser in number were also observed in the identical mixture kept in dark.

It is interesting to note that the microstructures of the mixtures exposed to light and kept in dark did not show the presence of any organic acid. The micro structures on hydrolysis showed the presence of myristic acid, oxalic acid and benzoic acid. The environmental media of these mixtures also showed the presence of these organic acids after hydrolysis. A few spots of some organic acids were recorded but these could not be identified in both the cases.

The micro structures formed in the exposed and unexposed mixtures showed the presence of sugars as mannose and sucrose. These on hydrolysis gave some more spots of sugars

TABLE 6

Mixture of Covered Flask (Dark)

S.No.	Rf Values in Phenol : H_2O	Rf Values in Butanol : Acetic acid : H_2O	Identification With Ammoniacal Silver Nitrate	Remark
Microstructures :				
Unhydrolysed	0·53	0·31	Mannose	White
	0·56	0·22	Sucrose	White
Hydrolysed	0·53	0·31	Mannose	White
	0·52	0·28	Glucose	White
	0·36	0·56	?	White
Environmental Medium :				
Unhydrolysed	0·53	0·31	Mannose	White
	0·32	0·48	?	White
Hydrolysed	0·53	0·31	Mannose	White
	0·36	0·56	?	White

TABLE 7

Phosphatase Activity in the Mixture Examined by Klett Summerson Photoelectric Colorimeter

S.No.	Boiled				Unboiled			
	0 min.	20 min.	40 min.	80 min.	0 min.	20 min.	40 min.	80 min.
Spontaneous (Control)	12	13	15	15	15	14	13	13
Uncovered (Light)	14	16	20	20	9	12	16	16
Covered (Dark)	30	32	35	35	16	15	15	15

along with those present in unhydrolysed ones. A similar observation was made in the environmental medium of the exposed and unexposed mixtures. More of the sugar was formed in the environmental medium in comparison with that of micro structures synthesised in the exposed mixture. However a larger quantity of sugar was present in the microstructures than in the environmental medium of unexposed mixtures.

The exposed and unexposed mixtures were examined for enzymic activity and more of the phosphatase activity was observed in the unexposed mixtures. This phosphatase activity was found to be destroyed on boiling the exposed and unexposed mixtures at 100°C for five minutes.

The greater enzymic activity in the mixtures kept in dark may be due to the stability of the peptides synthesised in these mixtures because of the mild source of energy affecting these mixtures and there is less of the thermodynamical possibility of the decomposition of these peptides in the mixture than in the similar exposed mixtures.

Summary

The mixtures containing amino acids as, glycine methionine, aspartic acid and cystein hydrochloride and anthracene as catalyst, on exposure to artificial light indicated the presence of some new amino acids other than originally added, organic acids, sugars and enzymic activity. The similar mixture kept in dark also indicated the presence of new amino acids, organic acids and sugars, but lesser in number as compared with exposed (light) mixtures. However enzymic activity was more pronounced in dark (unexposed) mixture than in light one, and in a lead chamber only the added amino acids were present.

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Aquifer Water Resistivity—Salinity Relations

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Abstract.—Aquifer water resistivity (R_W)-ionic concentration relations are briefly discussed. The application of some R_W estimation methods to forty-five N.S.W. water samples demonstrates that, in the absence of ionic information, the solutions of the forward and inverse estimation problems could contain large errors. Much work remains to be done in correlating R_W and concentration in N.S.W. aquifers.

Introduction

In recent years it has been recognised in hydrogeological investigations that the quality of ground water is of nearly equal importance to quantity. In specifying the quality characteristics of water a complete statement requires chemical, physical and bacterial analyses. Griffin (1964) has discussed the quality classification of domestic, agricultural and industrial water.

Electrical conductivity (EC) and its reciprocal resistivity (R_W) measurements bear a relation to the concentration of all inorganic constituents present in a water sample. Such measurements are principally a function of the mobilities and concentrations of the various ions in solution at a given temperature. The simple EC or R_W determination is the best single field method for assessing water quality. EC has become a frequently measured hydrogeological parameter. The parameter R_W is employed in the surface and subsurface electrical methods of applied geophysics in the fields of hydrogeology, mining and petroleum technology. For R_W in ohm metres and EC in micromhos per cm.:

$$R_W = \frac{10{,}000}{EC}$$

The term "salinity" of a water refers to its total soluble salt content in parts per million (ppm) by weight. A concentration of one ppm is equivalent to one milligram per litre or 0·07 grains per Imperial gallon. A frequent procedure in applied geophysics is the estimation of salinity from R_W determinations. Less commonly, R_W values are calculated from salinity information. In this paper estimation methods will be considered. The estimation accuracy of some methods will be investigated by applying the methods to published data on New South Wales groundwaters.

R_W—Ionic Concentration and Composition

The ion composition and ion concentration of underground water are both highly variable. With depth the temperature of such water can vary significantly. R_W varies with concentration in that it affects the activities and degree of dissociation of the various ions present in solution. Ionic mobility increases with temperature, hence an inverse relation exists between R_W and temperature.

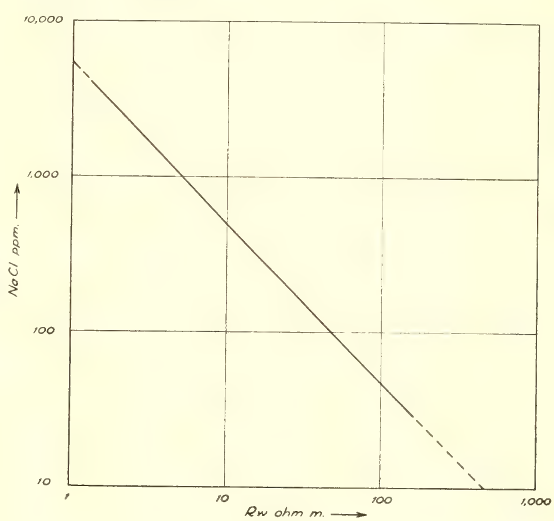

Fig. 1

Variation of electrical resistivity of sodium chloride solution with concentration in p.p.m. at 25° C. (Data from International Critical Tables.)

For sodium chloride solutions analytic expressions relating R_W to ion mobilities and concentrations are well known (e.g. Heiland, 1946, p. 637) but graphed relations are more suitable for routine use. The usual R_W-concentration charts supplied on request by geophysical well logging contractors are un-

suitable for hydrogeological purposes because R_w values terminate at too low a value. In addition such charts are for pure sodium chloride solutions which are not especially common aquifer waters in New South Wales.

In Fig. 1 is shown the variation of the electrical resistivity with concentration of sodium chloride solution at 25°C. The R_w values are from the International Critical Tables (1929) and cover the range of usual interest in hydrogeological work. The effect of temperature on R_w for sodium chloride solutions was determined by Arps (1953). The temperature effect is of considerable importance. Arps, whose study was necessary as discrepancies had been found in existing charts, discovered a nearly linear relationship between temperature and the ratio

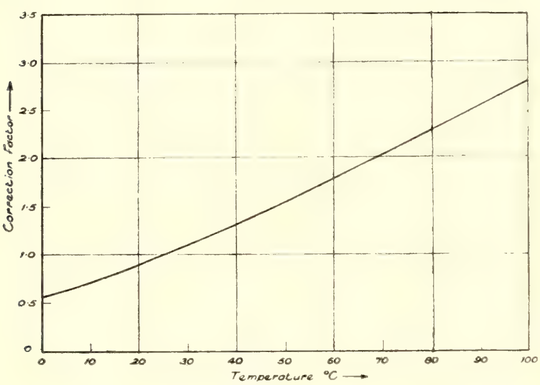

Fig. 2

Correction factor to convert R_w to 25° C.

of R_w at 32°F. to R_w at t°F. The equation of the relationship as determined by the method of least squares was:

$$R_w\ (32°) = 0{\cdot}022906\ R_w\ (t°)\ [t + 6{\cdot}77]$$

In order to convert R_w measured at t_1°F. to R_w at t_2°F. the above relation reduces to:

$$R_w\ @\ (t_2°) = R_w\ @\ (t_1°)\ \frac{t_1° + 6{\cdot}77}{t_2° + 6{\cdot}77}$$

Established practice is to express R_w at 25°C. (77°F.) for comparison and interpretation. Fig. 2 gives the necessary correction factors for this. This figure should also suffice for multi-ion waters. Richards (1954) gives more precise corrections if required.

For waters other than simple sodium chloride solutions (the usual case in New South Wales) different procedures are followed to obtain R_w from concentration or more commonly concentration from R_w. For fresh waters the relative contribution to conductivity of the ion compounds other than sodium chloride becomes very important (Ono, 1959). The restivity of a solution of two or more salts depends upon the relative concentration of each and upon the tendency of the ions to join to form more complex ions having a greater mass and smaller electric charge. For waters rich in ions with mobilities different from the sodium and chloride ions, especially if they contain bicarbonate, carbonate, sulphate and magnesium ions, the use of Fig. 1 may result in considerable error. Because of the nature of the variables involved, no simple estimation method can be entirely satisfactory for all ionic combinations and concentrations possible in aquifers. A dichotomy into a forward and an inverse problem is instructive. The forward problem —determining R_w from a knowledge of concentrations of the particular ions—can be solved by employing the appropriate equations of physical chemistry. However the inverse problem—determining concentrations from R_w —is incapable of unique accurate solution without auxiliary information on the type and quantity of ions present. The inverse problem is the real one in ground water geophysics. Reliable auxiliary ionic data are rarely available. To facilitate work in practice, a given relation is usually employed for the solution of both the forward and inverse problem.

Some R_w Estimation Methods

Conaghan and Harrison (1956), from chemical analyses and conductivity measurements on the waters of twenty five wells and eight surface waters in the Upper Hunter area of New South Wales, concluded that the following empirical equation obtained:

$$\text{Conc. (ppm)} = 1{\cdot}14\ EC_{(20°C)} - 15{\cdot}4Cl$$

where Cl is the chloride anion concentration. Conaghan and Harrison pioneered the use and development of the EC parameter in groundwater investigations. Their 1956 publication is an abridged version of an unpublished New South Wales Geological Survey Report. In the Report pertinent physical-chemical relations are discussed and a thorough review of the literature to that date (1948) is included.

An estimating formula commonly used by groundwater workers for R_w in the range of 2 to 100 ohm m. is $R_w = 100/T$ (Todd, 1959, p. 181) where T is the ionic sum i.e. half the sum of anions and cations in equivalents per million (epm). One epm of an element or ion is exactly equal in combining power to one epm of another element or ion. The epm values are obtained by dividing the ppm concentration

values of the constituents by the appropriate equivalent or combining weights. Another well known estimation method for the same resistivity range is $R_W = 6500/\text{conc. (ppm)}$. An approximation sometimes used in Australia is $R_W = 5000/\text{conc.}$ at 20°C (Wiebanga and Jesson, 1962).

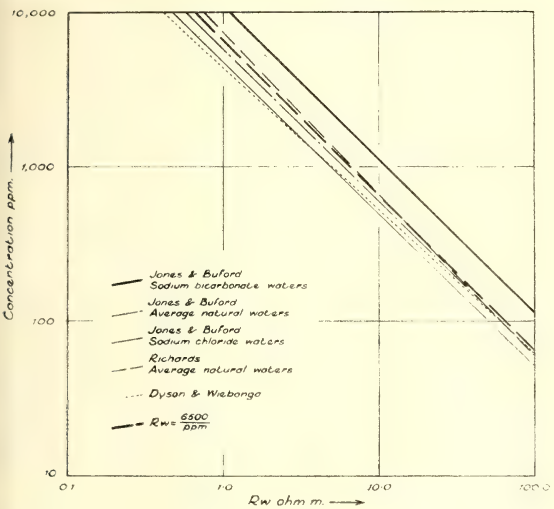

FIG. 3

Some R_W-Ionic concentration relations (25° C.).

Dunlap and Hawthorne (1951) developed a method for reducing the chemical composition to an equivalent sodium chloride composition. The ppm concentration of each ion is reduced to an equivalent sodium chloride salinity by means of conversion factors. For the sodium, potassium, calcium, magnesium, chlorine, sulphate, bicarbonate, carbonate and hydroxyl ions the factors are 1·00, 1·00, 0·95, 2·00, 1·00, 0·50, 0·27, 1·26 and 5·10 respectively. The factor for sulphate is raised to 0·55 when total concentration exceeds 10,000 ppm. Martin (1958) determined that the Dunlap and Hawthorne factors were relatively independent of temperature but varied considerably with changes in concentration.

Richards (1954) investigated a relation between R_W and the concentration of various average natural waters. This relation is plotted in Fig. 3.

Jones and Buford (1951) presented R_W-salinity data on sodium chloride, average natural and sodium bicarbonate waters. These data also are shown in Fig. 3.

Dyson and Wiebanga (1957) found:

$$\log \text{conc. (ppm)} + 0{\cdot}92 \log R_W = 3{\cdot}68$$

This relation was established for some Northern Territory waters at 20°C. These waters had a relatively high sulphate and chloride content when concentrations exceeded 1600 ppm and a relatively high carbonate content when concentrations were less than 500 ppm. Their relation is shown in Fig. 3.

Logan (1961) devised an empirical estimation technique in which only the nature of the principal anion and the epm value are considered. Logan's data for "normal" (bicarbonate), chloride and sulphate waters are presented in Fig. 4.

Discussion

Of the estimation methods mentioned, the 100/T, Dunlap and Hawthorne, Logan—normal, 6400/ppm and Jones and Buford average natural relations are deemed methods of general utility and applicability. To test the efficacy of these general estimation methods forty three chemically analysed groundwaters were chosen at random from the published data of Horbach (1965, 1967) and Conaghan (1961). In addition one water was taken from Conaghan and Harrison (1956) and one water from the Water Conservation and Irrigation Commission's data on groundwaters of the Forbes district. The results of EC measurements on all waters were also available.

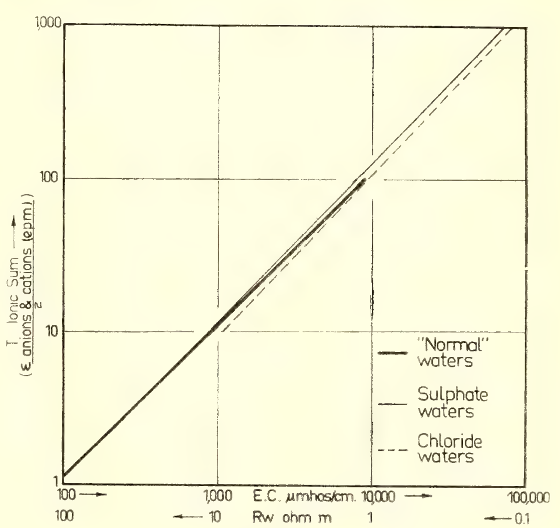

FIG. 4

R_W (and E.C.) at 25° C.—Ionic sum relationships. (*After* Logan, 1961.)

In the Appendix the sample number, R_W value and dominant anion of each water are given. It will be noted that the bicarbonate anion is dominant in twenty seven of the

samples and the chloride ion dominates in the remaining eighteen. R_w values range from 0·45 to 64·5 ohm m. Waters from deep and shallow bores in the Sydney, Murray, Clarence and Great Artesian Basins together with waters from shallow bores in coastal and inland river deposits are included.

TABLE 1

Estimation Method	Percent Average Deviation	Percent Average Bias
$\frac{100}{T}$	8	—5
Dunlap and Hawthorne	10	—4
Logan	11	+11
$\frac{6400}{ppm}$	14	—11
Jones and Buford	17	—16

In Table 1, for each of the five general estimation methods, the average deviation of calculated from measured R_w values are listed with the average bias of the calculated values. To provide a better comparison of the methods, the results are given in the form of average percentage errors. An estimation error of 1·0 ohm m. for a measured R_w of 4·0 ohm m. would not be as serious as an error of equal magnitude for an R_w of 2·0 ohm m.

It can be seen that the 100/T method was the most satisfactory followed by the Dunlap and Hawthorne and Logan-normal methods. It should be remarked that an 8% average deviation and a +7% bias was obtained when the Logan-normal curve was used for the twenty seven bicarbonate waters only. An 8% average deviation and a +8% bias were obtained when the Logan-chloride curve was applied to the eighteen chloride waters only. These methods require knowledge of the nature and quantity of ions present.

The 6400/ppm and Jones and Buford average natural methods gave poorer results. These two methods require a knowledge of quantity of ions and an indication that the water is not of abnormal type.

In the examples the forward problem has been considered. Attempts to solve the inverse problem would lead to even larger uncertainties in the absence of data on the nature and amounts of ions in the water.

For the solution of the inverse problem it is considered reasonable to predicate :

1. When the nature of the dominant anion of the waters in question is unknown and no assumptions as to the dominant anion nature are possible then, until a better correlation is available, the 6400/ppm relation should be used if concentration in ppm is required. To obtain concentration in epm the $R_w=\frac{100}{T}$ or Logan normal curve should be used. It should be remembered that to convert epm to ppm requires some assumption of ions present in the water.

2. When some knowledge as to the nature of the dominant anion is available the Logan curves for a particular dominant anion should be used.

3. In particular localities for particular aquifers where the R_w-ppm equation is known, e.g. the Conaghan and Harrison relation for the Upper Hunter groundwaters, then such a relation should be used.

In New South Wales the state of knowledge as indicated by statement 2 above would obtain at the present time for most areas. As chemical analyses and R_w data accumulate the situation will improve.

Generally, groundwater from a particular aquifer in a specific area is nearly constant in chemical quality. Dissolved solids present can be correlated with the mineralogy, texture and structure of an aquifer, the position of the well with respect to recharge areas and the rate of movement of interstitial waters which would depend on climate, surface topography and subsurface structure. Extensive psammitic aquifers commonly yield water of a fairly uniform chemical composition or a composition that changes uniformly with location.

In most areas systematic changes, if any, in the family of ions generally accompany changes in the total dissolved solids. Thus the interpretation of groundwater R_w values in terms of probable concentrations and kinds of important ions is usually feasible by geological and geographic interpolation and by extrapolation between or from available well control.

Conclusions

Whilst no detailed conclusions can be drawn from the results of the methods' applications to only forty five New South Wales waters the following observations are considered valid :

1. Large errors may result in attempts to solve both the forward and inverse problems if no information is available as to the nature of dissolved solids in waters.

2. Every effort should be made to obtain the requisite ionic information before interpretations are commenced.

3. R_w-concentration relations should be formulated for particular areas as the necessary data become available.

Appendix

New South Wales Department of Mines Chemical Laboratory sample number; measured R_w value ohm metres at 25°C; dominant anion: B bicarbonate, C chloride.

63/479, 3·5, C; 63/486, 1·1, C; 63/490, 3·3, C; 63/500, 1·3, C; 63/513, 34·6, B; 62/566, 33·3, B; 62/568, 64·5, B; 63/4106, 6·3, C; 63/4109, 56·8, C; 63/5201, 23·6, B; 62/2093, 16·8, B; 62/483, 2·8, B; 63/2951, 0·67, C; 63/2965, 9·2, B; 63/4955, 15·3, B; 63/4956, 4·0, B; 62/321, 18·6, B; 62/1630, 23·2, B; 62/1776, 9·2, C; 63/2655, 10·9, C; 63/3187, 1·7, B; 63/4623, 39·1, B; 63/5166, 1·3, B; 62/2148, 9·1, B; 62/2149, 8·5, B; 62/2150, 6·7, B; 62/2151, 9·1, B; 64/1776, 1·6, C; 64/1780, 0·6, C; 64/1783, 5·9, B; 64/2148, 0·45, C; 64/2795, 1·1, C; 64/2807, 41·5, B; 64/362, 19·1, B; 64/564, 41·5, C; 64/4598, 0·88, C; 64/542, 6·9, B; 64/543, 9·9, B; 58/1037, 21·2, B; 58/1668, 3·7, C; 58/1017, 11·9, B; 58/2049, 2·1, C; 58/1666, 5·6, C; 48/2538, 8·8, B; W.C.I.C. Bore 14824, 16·1, B.

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The Stratigraphy of the Putty-Upper Colo Area, Sydney Basin, N.S.W.

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ABSTRACT.—The outcropping sediments of the area mapped are of Triassic age and include the Wianamatta Group, Hawkesbury Sandstone and Narrabeen Group.

The Narrabeen Group represents the oldest outcropping sediments of the area and up to 600 feet are exposed, though, only rarely are more than 300 feet exposed at any one locality. It consists of labile and sub labile sandstone, siltstone, mudstone and scattered chocolate claystone.

The overlying Hawkesbury Sandstone attains a maximum thickness of 950 to 1000 feet from Webbs Creek to Upper Colo and extends over almost the whole of the area mapped. It consists of quartz sandstone and minor scattered sub-labile sandstone with rare siltstone interbeds up to 30 feet thick.

Of the Wianamatta Group only a veneer remains. It is restricted in outcrop to the vicinity of the Putty Road from the Culoul Range southward. It consists of siltstone and fine grained flaggy, labile sandstone.

Structurally the area is dominated by the Lapstone Monocline extending from Upper Colo to Kindarun Mountain. Gentle eastern dips occur west of the Lapstone Monocline and a series of open folds plunging southwards occur east of the Lapstone Monocline.

Basic igneous necks and caps are scattered throughout the area but are most common north of 33°00'S in the vicinity of Putty and Kindarun Mountain.

Introduction†

The earliest contribution to the knowledge of the geology of the area was that of Carne (1908) who worked over the western half of the area north of 33°15'S latitude and described many basic plugs and caps of the area. He also refers to a few chocolate claystone localities.

Lovering (1954) recorded the presence of Ashfield shale capping the Wheelbarrow Ridge near Colo Heights.

Crook (1956) studied the Kurrajong-Grose River district and by air photo interpretation extended his work to cover the country west of the Putty Road and south of 33°15'S. The work was used in compiling the accompanying maps, but numerous detailed modifications, as a result of the author's field work, were necessary.

Raggatt (1938) studied the Triassic sediments east of Mangrove Creek. His sub-divisions of the Narrabeen Group could not be applied in the area covered by this paper.

McGarry and Rose, of Australian Oil and Gas Corporation carried out reconnaissance work in the Putty and Howes Valley districts. The results of this work are unpublished.

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† In this paper the 1 : 63,360 sheet areas mapped are :—Mount Yengo, Mellong, St. Albans. This covers part of both the Sydney and Singleton 1 : 250,000 sheet areas.

Regional Stratigraphy

The Triassic sediments are the oldest outcropping rocks in the area studied and consist, in general, of quartzose and sub labile sandstone with less common siltstone and mudstone. Subdivisions of the sequence in areas adjoining that studied have been proposed by Lovering (1954) for the Wianamatta Group, Crook (1956) for the Narrabeen Group of the Kurrajong-Grose River district, and Raggatt (1938) for the Narrabeen Group of the Gosford-Morisset district. Of these, Lovering's and Crook's subdivisions have been found to be applicable in the area studied.

The sequence examined is summarised in the following table.

Thicknesses quoted above are maxima for the area studied and are field measured sections with the exception of the Grose Sandstone which was the thickness recorded in Exoil A.O.G., Kurrajong Heights No. 1 well*, the bore data being made available by the Bureau of Mineral Resources in accordance with the Petroleum Search Subsidy Act.

Figures 2 and 3 show a number of measured sections with the probable NS and EW formational equivalents. These are discussed under " Correlation and Comments ".

* Following their first appearance in the text, wells will be referred to only by the name of the locality after which they are named.

The outcropping Triassic rocks of the area are known, from A.O.G., Mount Murwin No. 1 and A.O.G., Mellong No. 1, to be underlain by the " Upper Coal Measures ". It is most probable that these in turn are underlain by " Upper Marine " sediments, as they outcrop in the Hunter Valley and along the western edge of the basin; they were also encountered in Kulnura No. 1 and the Kurrajong Heights wells. Below the " Upper Marine " sediments a southern extension of the Greta Coal measures and the " Lower Marine " Dalwood Group may underlie the northern parts of the area, but their absence in the Kurrajong well possibly places limits on their southward extension.

Table 1

Age	Stratigraphy	
Quaternary—Recent	Sands and gravels along the courses of present streams	
Post Triassic	Basic volcanics, dykes, necks and flows	
TRIASSIC	Ashfield Shale of the Wianamatta Group (75 feet)	
	Hawkesbury Sandstone (950 feet)	
	Narrabeen Group West	East
	Burralow Formation (450 feet)	Undifferentiated
	Grose Sandstone (1385 feet)	Undifferentiated
	Caley Formation (217 feet)	Not observed

Underlying the Permian sequence it is probable that basic, then older acid volcanics occur of possible Carboniferous age. From outcrop in the Hunter Valley, as well as the A.O.G. Loder No. 1 well, and Planet's East Maitland No. 1 well, it is evident that the Dalwood Group contains a considerable thickness of basalt and tuffs and overlies the Carboniferous acid volcanics of the Upper Kuttung Group. Along the western margin of the basin the tuffs at Rylestone overlie the Upper Devonian sandstone unconformably and are conformably overlain by the Permian sediments (Personal communication, Dr. A. J. T. Wright), and have lithological similarities with the volcanics of the Upper Kuttung Group (Day, 1961). South of the area studied, A.O.G., Kirkham No. 1 and the Kurrajong Heights wells (Stuntz *et al.*, 1963) (Stuntz, 1965) terminated in basic and acid volcanics.

Formation Descriptions

Narrabeen Group, Wilkinson 1887

This group occurs throughout the whole of the area studied, outcrops being more common toward the north.

The area studied lies between two areas which have had different stratigraphic subdivisions recognised within them, those of Raggatt east of Mangrove Creek, and those of Crook southwards from Upper Colo. Fig. 1 shows the probable E-W correlation across the basin.

East of the Mount Murwin-Webbs Creek anticlines, individual sandstones are up to 100 feet thick, but are not persistent; they thicken or thin and split over short distances as indicated by the E-W Sections 4 to 19 on Fig. 2, between Mogo Hill and Melon Creek, west of Higher Macdonald.

Along the Webbs Creek and Macdonald River systems south of 33°15′S, less than 150 feet of the Group exposed; north of 33°12′S 300 to 600 feet of the Group is exposed, however, neither Crook's nor Raggatt's subdivisions are recognisable in this area. This is evident from examination of the stratigraphic sections measured in the district from which it can be seen that correlation between successive sections is most difficult (Fig. 3).

North from Colo, Crook's subdivisions are workable, but only to the west of the Webbs Creek and Mount Murwin anticlines. Following these formations as defined by Crook is progressively more difficult towards the north. At 33°00′S it is evident that the dominantly shale lithologies of the Burralow Formation are being replaced by up to 50% sandstone, however, the Grose Sandstone provides a recognisable base for the Formation. A persistant, prominent sandstone about halfway between the base of the Hawkesbury Sandstone and the top of the Grose Sandstone, is possibly a correlate of the Tabarag Sandstone Member and can be followed from 33°15′S to 33°06′S. At this point the increasing occurrence of additional sandstone units makes it progressively more difficult to distinguish the member. At Mount Wirraba and west of it, the Burralow Formation is not recognisable, the top of the Narrabeen Group being almost all sandstone (See Section 8, Fig. 3).

To the east of the Mount Murwin-Webbs Creek anticlines no subdivisions within the group have been applied. Chocolate claystones are common throughout the area but are usually very poorly exposed, or are concealed.

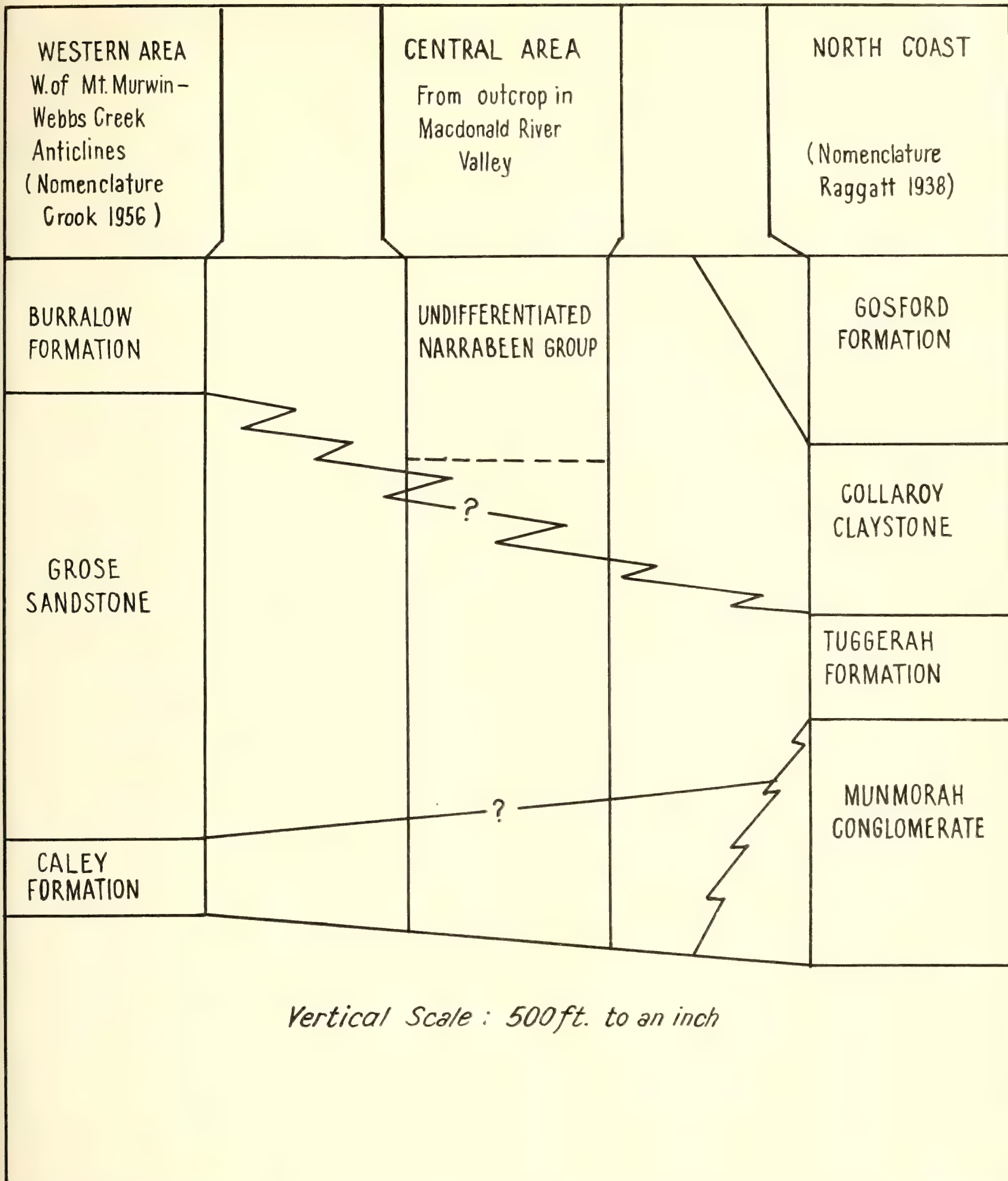


FIG. 1—Probable E-W correlation.

For descriptive purposes the area will be divided into two sections, one west of the Webbs Creek-Mount Murwin Anticline where Crook's subdivisions can be applied, and a second, east of the anticline where no subdivisions will be applied.

CALEY FORMATION, CROOK 1956

Although the area where this formation was examined is some miles north from the nearest locality where Crook records it, it so closely resembles his description that there is little doubt that it is the same formation.

It outcrops only in the extreme west of the area mapped where it conformably overlies the Lithgow Coal Measures. During a brief reconnaissance trip down the Wolgan and Capertee Valleys it was examined and found to consist of interbedded grey mudstone and siltstone up to 15 feet thick with scattered labile sandstone, commonly three to six feet thick, but rarely up to 15 feet thick. Current bedding was not observed at Wolgan Gap, but both planar and festoon bedding was present at Newnes in the Wolgan Valley. The sandstones were fine to coarse grained and, in addition to quartz, contained a considerable percentage of rock fragments; these were white, angular and deeply weathered in the outcrop samples examined; the cement consists of white clay. Bands of pebble conglomerate, especially at Wolgan Gap, contained abundant rock fragments, most of which were low grade metasediments that are readily available from the Palaeozoic rocks further west.

The base of the formation coincides with the top of the Katoomba seam and it is overlain by the Grose Sandstone. At the top of the formation, green and chocolate claystones commonly occur, there being 15 feet at Wolgan Gap and 32 feet at Newnes. The formation thickens from 135 feet at Wolgan Gap to 217 feet at Newnes over an east-west distance of only eight miles, clearly showing the rapid thickening basinwards. The thickness recorded in the Kurrajong Heights well was 250 feet, revealing only slight thickening basinwards from Newnes, while the Mount Murwin well records 483 feet, almost double the thickness at Kurrajong Heights.

Grose Sandstone, Crook 1956

The Grose Sandstone consists of labile sandstone with scattered discontinuous siltstone interbeds. In the area studied it outcrops only in the gorge of the Colo River and its tributaries. It is exposed well north of Upper Colo on the Colo River, west of Six Brothers Trig near the junction of the Capertee River and Wollemi Creek (730 feet exposed). A second locality is along the military track for four wheel drive vehicles where it runs for about one mile upstream along Wollemi Creek from the junction with Putty Creek, and, thirdly, west of Cobcroft Trig where 372 feet are exposed. In the valleys of the Wolgan and Capertee a considerable thickness of the formation is to be seen. Weathering has removed all signs of the formerly overlying Burralow Formation or Hawkesbury Sandstone in this area, so the following sections represent only the eroded remnants of the formation. At Wolgan Gap, 230 feet remains, overlying the Caley Formation. It consists of sandstone showing common planar type current bedding from one foot six inches thick to three feet thick, and, particularly near the base, scattered thinner planar type current bedded units from three inches to 12 inches thick.

At Newnes, 737 feet of the formation remains, of which the lower 288 feet closely resemble that seen at Wolgan Gap. Above this lower 288 feet there is a break in outcrop for 44 feet in which sandstone talus was so common, that no suggestion of siltstone, claystone, or any other rock type could be found in situ. This interval of no outcrop is sufficiently widespread to be recognisable on either side of the Wolgan Gorge and can be seen extending down stream to the Devil's Pinch (Glen Davis, 278005).

Above this break a further 230 feet of sandstone occurs. It is characterised by the predominance of planar type current bedded units generally from three to nine inches thick with scattered beds up to one foot six inches thick. This contrasts with the thicker units of the lower 288 feet where beds 10 to 20 feet thick predominate. Where the Grose Sandstone has been examined along the Colo River and Wollemi Creek, current bedded units up to one foot thick are predominant with rare units up to three feet thick.

On the basis of field work, no estimate can be made of the maximum thickness of the formation. In two localities over 700 feet are exposed—737 feet at Newnes and 730 feet at the junction of the Colo and Capertee Rivers; these sections are incomplete. In the Kurrajong Heights and Mount Murwin wells the thickness of the sandstone correlatable with the Grose Sandstone is 1385 feet and 1335 feet respectively. About 1200 feet of the formation occur in the A.O.G. Mellong well (personal communication, J. Stuntz, A.O.G.). These thicknesses are about twice the maximum of 700 feet proposed by Crook from two partial sections measured in the Grose Valley, where Crook's section shows that the formation is thinning westward.

Burralow Formation, Crook 1956

This formation outcrops extensively to the west of the Putty Road, and is the uppermost formation in the Narrabeen Group. It overlies the Grose Sandstone, is overlain by the Hawkesbury Sandstone and is from 300 to 450 feet thick. It is distinguishable from the Hawkesbury Sandstone by the dominantly siltstone and

claystone lithologies with scattered lithic sandstone and, north of the 33°10′S latitude, by the presence within the Burralow Formation of scattered beds of characteristic polymictic conglomerate. These conglomerates are rarely more than one pebble thick where observed in Mellong Range-St. Albans areas, but to the north the units become thicker and more common until in the Howes Mountain-Sugarloaf Hill (39319404) area they are up to 12 feet thick. In the south the pebbles consist mainly of black, red, pastel blue and green jasper with some pale smoky grey, milky and colourless quartz pebbles of up to two inches diameter. They are slightly elongate and well rounded. At Putty and Mogo Hill (Section 19) pebbles of obvious acid igneous origin and other weathered fine grained rock fragments of "chalky" appearance occur. At Reedy Creek, further north, scattered quartz porphyry pebbles, and increasing amounts of weathered "chalky" rock fragments occur with less jasper and few milky or colourless quartz pebbles. At Howes Mountain, quartz, porphyry and acid volcanic cobbles occur in beds which are commonly two to three feet thick and rarely as much as 12 feet thick.

Lithic sandstones are common only north of the Culoul Range, south of this, quartz sandstones predominate; at Upper Colo these quartz sandstones are very similar, even in thin section, to those of the Hawkesbury Sandstone. Current bedding of both the planar and festoon type are common in the sandstones of the formation.

About 150 to 200 feet below the Hawkesbury Sandstone, a sandstone occurs which is possibly equivalent to the Tabarag Sandstone Member of Crook (1956). It can be followed from the Culoul Range to 33°05′S, but north of this point the greater proportion of sandstone in the section makes the Member increasingly difficult to distinguish. To the west, the formation as a whole becomes increasingly difficult to recognise because of the increasing proportion of sandstone present. At the western edge of the area, between 33°00′S and 33°15′S the proportion of sandstone is so great that the formation is extremely difficult to distinguish from the Grose Sandstone below or the Hawkesbury Sandstone above. The boundaries shown between 33°00′S and 33°15′S were determined from aerial photo interpretation with known ground control in various localities. The map shows both the lower and upper boundaries to its western edge, but the Grose Sandstone-Burralow Formation boundary is very approximate at the western edge and is practically unrecognisable in the field. The Hawkesbury-Narrabeen boundary in the field is a sandstone-sandstone boundary which, even in the most favourable circumstances, is subject to interpretation.

The total thickness of the Burralow Formation varies from 300 feet to 450 feet. Whether the formation thins out or passes into sandstone towards the west is debatable, but the author thinks that passing into sandstone westwards is not only to be expected, but is confirmed by the Section 8 measured at Mount Wirraba. Here, the Hawkesbury-Narrabeen boundary, based on the change in sandstone types is at 1550 feet A.S.L., whereas the top of the Uppermost chocolate claystone is at 1260 feet A.S.L. Polymictic conglomerates were not found. Above the chocolate claystone scattered grey siltstone occurs, but sandstone is more common up to the proposed base of the Hawkesbury Sandstone, above which the massive and current bedded quartz sandstone of the formation continues to the base of the basalt capping Mount Wirraba.

Undifferentiated Narrabeen Group

The undifferentiated Narrabeen Group is to be found east of the Webbs Creek and Mount Murwin anticlines. Similar lithologies to those observed in the Burralow Formation are observed also along the Macdonald River and its tributaries and the upper reaches of Webbs Creek near its junction with Rush Creek. They consist of lithic sandstone, siltstone, chocolate and green claystone and polymictic conglomerate. Sandstones up to 100 feet thick occur, rarely with a chocolate claystone band up to two feet thick interbedded with the sandstone. An example of this can be seen in the measured sections between the Ivory Creek-Melon Creek junction and Mogo Hill (Sections 14, 15, and 16, Fig. 3). Chocolate claystone can be found in any section examined; it is not confined to any particular horizon and is just as common 500 feet below the Hawkesbury Sandstone as 100 feet below it. Polymictic conglomerates occur, but they have not been seen south of St. Albans. This is probably because of the small stratigraphic interval exposed. The most southern locality from which they have been found is one to two miles north of St. Albans and they occur in thicker and more numerous beds the further north one seeks them. Rarely is more than 100 feet of the Group exposed along the Macdonald River south of St. Albans. Around Upper and Higher Macdonald the conglomerates are sufficiently common to be

very useful in determining the base of the Hawkesbury Sandstone. A description of the pebbles and their geographic variation is given in the petrographic description of the Burralow Formation and will appear in a forthcoming paper.

The sandstones within the exposed part of the Narrabeen Group are discontinuous, as demonstrated by the seven stratigraphic sections measured between Mogo Hill in the east and Melon Creek in the west (Fig. 3) the section line being about 13 miles in length. A 100 feet thick sandstone body will split into a number of smaller units and lens out into shale over very short distances. It is doubted that even these 100 feet thick, apparently non shaley sandstone bodies would, if examined in a 100% exposure or in a diamond drill core, be found to be devoid of shale bands.

Sedimentary structures, including both festoon and planar current bedding and, in one locality current ripples, were observed. The current ripples, which have not been observed elsewhere in the area, occur about two miles north of Higher Macdonald in the bed of Thompsons Creek. The planar cosets of current bedding can be as much as 10 or 15 feet thick, though these thicker units are by no means as common as in the Hawkesbury Sandstone.

In the Fernances-Mogo Hill area, the base of the Hawkesbury Sandstone becomes very difficult to recognise. This is because it is commonly a sandstone-sandstone boundary. At Mogo Hill polymictic conglomerates occur 90 feet below a 130 feet thick sandstone section. The highest conglomerates are usually no more than 70 or 100 feet below the top of the Narrabeen Group, so the base of the Hawkesbury Sandstone would be placed below the 130 feet sandstone section. However, the sandstones appear more lithic than is normal in Hawkesbury Sandstone and in thin section contain only 45% quartz—the remainder being rock fragments and matrix. The boundary is probably at the top of the siltstone which overlies the 130 feet of sandstone resulting in the topmost conglomerates being 270 feet below the Hawkesbury base.

Erosion of the top of the Group before deposition of the Hawkesbury Sandstone is evident in the lower reaches of the Macdonald River near its junction with the Hawkesbury River. Washouts over 100 feet deep and covering an area of half a square mile are recognisable, in particular at (39458775). They have not been recognised elsewhere in the area.

Hawkesbury Sandstone, Clarke 1848

This formation occurs throughout the whole of the area studied. It consists of quartz sandstones which are light grey to creamy white in colour with a white clay cement. There is always abundant colourless to milky subangular quartz with rare scattered graphite and dark black and brown grains present. The grain size is dominantly medium to coarse but may be fine or very coarse.

Two distinct types of conglomerate occur. The first type consists of masses of angular, often rectangular, granules and pebbles of quartz ranging from one-quarter to three-quarters of an inch in diameter; the thickness of a single unit often being as much as 15 feet. These units often grade from pebble size at the base to fine sand size at the top. The second type of conglomerate consists of well rounded oval pebbles from one to two inches in diameter with rare ones up to six inches in diameter. They are commonly composed of colourless to milky quartz with very rare smoky grey pebbles. The units are very thin, usually only one pebble thick, units of two or three layers were rare.

A small percentage of silstone occurs; it is usually mid-grey to buff in colour and rarely exceeds 20 feet in thickness. Bands up to four feet thick are to be found in any section measured. Total thickness of siltstone in a 500-foot section is usually about 5% and rarely exceeds 10%.

Compared with the Wianamatta Group, siltstone, those of the Hawkesbury Sandstone are much lighter grey in colour, are much more sandy and do not form dense black soils or support prolific vegetation. Notable occurrences of these shales are along the Old Great North Road leading NNW from Wisemans Ferry near the road junction to Putty township on the Putty Road and about halfway along the Upper Colo-Colo Heights road. In all cases they overlie and are overlain by undeniable Hawkesbury Sandstone.

Current bedding is very common in the Hawkesbury Sandstone. It is dominantly of the planar or torrential type and occurs in units commonly up to six or rarely eight feet thick but may be even thicker. Rare beds of the festoon type occur; they average from three to nine inches in thickness and seldom exceed two feet. The angle of dip of foresets is commonly 18 to 24 degrees, but ranges from 15 to 30 degrees. The thinner beds are commonly found in finer grained sandstone and the dips of the foresets are at a lower angle than the thicker

units which are usually more coarse grained and made up of granule or even pebble size material. The foresets dip predominantly toward the NE and occasionally to the north ; rarely they may have quite anomalous dips. In such localities, additional observations at higher and lower stratigraphic levels invariably show that the majority of the units dip to the NE. This predominant dip direction of foresets in the planar type of current bedding is maintained throughout the whole of the area from Colo and Wisemans Ferry in the south to Howes Mountain in the north.

The total thickness of the formation varies greatly over the area. The greatest thickness appears to be near the junction of Rush Creek and Webbs Creek where the base is at 170 feet, while the hill immediately south is still Hawkesbury Sandstone at its crest at 1020 feet, giving a total thickness of over 950 feet for the formation. This is the maximum thickness recorded for this formation in the Sydney Basin. Further to the NW, between Dooli Creek and the Culoul Range, the thickness appears to be about 750 feet, but the dip thereabouts is not clear and the total thickness could be less. Further south, at Colo heights between the base of the Wianamatta Group and the Colo River, 855 feet of the formation is exposed—the section being measured along strike over a distance of three miles. Consideration of structure contours determined on the base of the Hawkesbury Sandstone and Wianamatta Group and the distance between the base of the section and the known base of the formation at Upper Colo, suggests that a further 50 to 100 feet of the formation is probably unexposed. Still further south the Kurrajong well encountered 750 feet of Hawkesbury Sandstone. The thickness of the formation above the well site is uncertain, because of the closeness of the Kurrajong Fault, but it would not be more than 50 feet. Thus the thickness of the formation would be about 800 feet at Kurrajong Heights. Further west, near Mount Tomah, between the base of the Wianamatta Group on the Bell Road and the Hawkesbury Sandstone base in Bowens Creek, the formation is only about 420 feet thick.

These fgures show a rapid thickenirg to the east from 420 feet near Mount Tomah to 750 to 800 feet alorg the Kurrajong Heights-Culoul Range line followed by a further thickening to over 950 feet at Colo Heights and the Webbs Creek-Rush Creek junction.

North of the Culoul Range it is impossible to measure the thickness of the formation because of the absence of Wianamatta Group. However, at Putty, between the Hawkesbury Sandstone base in Snake Valley and the Putty Rock trig, which is still in Hawkesbury Sandstone, a thickness of 486 feet remains. Still farther north, between Darkey trig and the Hawkesbury base in Darkey Creek, 321 feet of the formation remains. A mile or so further north the southern dip takes the base of the formation above general ground level.

Wianamatta Group, Clarke 1848

Only a veneer of this group remains and occurs as ridge cappings in the area studied. It consists of dark grey fine grained siltstone with interbeds of thin lithic sandstone up to two feet thick ; flaggy coarse siltstone and very fine grained sandstone one to three inches thick are common, separated by soft fissile shale. The group forms a characteristic dark black soil which supports very dense vegetation. It outcrops in isolated patches along the Wheelbarrow Ridge which runs between Portland and Colo Heights and along the Culoul Range. An outlier occurs around Hockeys Flagstaff trig to the NW of the Culoul Range.

The group outcrops thinly along the tops of these ridges. Often there is no way of determining whether the outcrops represent the Passage Beds (Lovering, 1954) or Ashfield Shale (op. cit.). This applies in particular along the Culoul Range. However, around Colo Heights and Hockeys Flagstaff Trig (36978985) where 50 to 75 feet of the Group occurs, there seem to be no Passage Beds, but instead there is an abrupt change from Hawkesbury Sandstone into Wianamatta Group siltstone. Lovering suggested (P175) that these occurrences probably belong to equivalents of the Ashfield Shale.

Additional siltstone occurrences to the north of Hockeys Flagstaff trig on the ridge at (36978985) and along the western end of the Parr Spur track, especially around Dry Rock (36458809) and to the south of it to (36358785) are not regarded as belonging to the Wianamatta Group. Many sandstone floaters occur through the siltstone which does not yield the black soil or vegetation characteristic of the Wianamatta Group and has a total thickness of only a few feet. These occurrences probably represent siltstone lenses high in the Hawkesbury Sandstone. The siltstone along the Old Great North Road, north east of Wisemans Ferry is overlain in places by up to 50 feet of undoubted Hawkesbury Sandstone.

Criteria for Recognition of the Hawkesbury-Narrabeen Boundary

The main mapping horizon in the area studied was the base of the Hawkesbury Sandstone. It was the only boundary sufficiently widespread to be of practical value. The base of the Wianamatta Group is restricted to ridge tops south of 33°15′S except for the small outlier at (36978985). A prominent siltstone horizon in the Hawkesbury Sandstone, outcropping along the Old Great North Road NE of Wisemans Ferry, was mapped, but it was always doubtful whether the siltstone on neighbouring hill crests was from a continuous horizon or a number of separate ones.

The lithologies regarded as diagnostic of the Narrabeen Group are listed below.

Chocolate Claystones :—These occur throughout the whole of the area studied. They rarely outcrop other than under most favourable circumstances such as in a creek bed, a recent land slide, or, occasionally, under sandstone ledges where mechanical undercutting may reveal them. Because they outcrop so poorly they are a rather unsatisfactory basis for determining the Hawkesbury-Narrabeen boundary.

Polymictic Conglomerates :—These provide by far the most practical criteria for use in the field. In particular they consist of jasper pebbles which do not occur in the Hawkesbury Sandstone and which resist erosion even when all other components have been destroyed. Where talus or soil alone can be found, jasper pebbles often remain on the surface of the ground and around tree roots. A detailed description of the jasper pebbles and the polymictic conglomerates and their geographic limits can be found in the foregoing description of the Burralow Formation.

Sandstones :—A sequence of fine grained sandstones, in regular beds one to three feet thick, commonly separated by thin siltstone interbeds is regarded as typical of the Narrabeen Group. Such sandstones are commonly soft and deeply weathered. Thickly bedded coarse grained units common in the Hawkesbury Sandstone are equally common in the thicker units of the Narrabeen Group. The thinner sandstone units of the Narrabeen Group are commonly much darker in hand specimens and contain more rock fragments and ferruginous material than samples from the Hawkesbury Sandstone. One must be very cautious, as sandstones from the Hawkesbury Sandstone can have quantities of graphite, ferruginous material and abundant white clay cement. A sandstone-sandstone boundary is somewhat unsatisfactory as it is always liable to different interpretations.

Siltstone :—In localities such as the lower reaches of the Macdonald River, especially at Wisemans Ferry, only a few tens of feet of the Group is exposed and no chocolate claystone or polymictic conglomerate are to be found. In such localities where in excess of 50 feet of siltstone can be found underlying known Hawkesbury Sandstone, there is strong evidence that the base of the Hawkesbury Sandstone is above the siltstone. This is significant even if neither chocolate claystone nor polymictic conglomerate can be found, as, in the Hawkesbury Sandstone, siltstone rarely exceeds 10 feet in thickness and only very rarely exceeds 20 feet in thickness in the area mapped.

Current Bedding :—The current bedding of the Hawkesbury Sandstone almost invariably dips to the NE and only rarely varies more than to the north or ENE. In the Narrabeen Group it dips to the ESE or S. The uppermost sandstone in the Putty district dips east but is overlain by chocolate claystone.

Outcrop :—In general, poor outcrop is found on slopes facing S or SW because of the lush vegetation and deep soil developed. This is probably because of the increased moisture and humidity in such protected areas. N and NW facing slopes are often bare or only covered with light brush and sparse soil cover. Thus they are more rewarding when examined in the field.

Correlation and Comments

Figures 2 and 3 show two east-west cross sections and one north-south. The correlation between 1 and 7 shows how the Burralow Formation can, with some difficulty, be followed along a north-south line west of the Lapstone Monocline. Difficulties were experienced in correlating sections, where insufficient of the Grose Sandstone was exposed to be sure that the sandstone at the base of a section was not another interbed in the Burralow Formation. Section 7 and the Mount Murwin well confirm the validity of the Burralow Formation and Grose Sandstone divisions of the Narrabeen Group. In particular, Sections 6 and 7 cannot be correlated except on the possibility of the Grose Sandstone occurring at the base of Section 6, as shown in Figure 3.

In spite of the difficulty in correlating these sections, it is doubted that Section 7, as shown on the cross section, is far from its correct position relative to the other sections. This is supported by Section 5 in which the thickness of the Burralow Formation is 405 feet. The underlying sandstone is known to be within the Grose Sandstone as the thickness of the sandstone unit increases to about 250 feet about two miles further up Wollemi Creek. Section 8, some three to four miles west of Section 5 and shown following Section 7 is included to demonstrate the "sanding up" of the Burralow Formation westwards.

Difficulty is experienced in recognising the Grose Sandstone-Burralow Formation boundary eastwards from the Lapstone Monocline. This is shown by the east-west section from Section 7 to Sections 9 and 10 thence east to Section 11. From these sections it appears that alternating sandstone-siltstone lithologies persist for at least the uppermost 500 feet of the Narrabeen Group. From the air photo interpretation between 33°00′S and 33°15′S, the Narrabeen Group throughout the Macdonald River system is seen to have produced a stepped relief on hillsides, indicative of alternating sandstone-siltstone lithologies. Over 800 feet of the Group is exposed along the Macdonald River at about 33°07′S. This indicates that the Grose Sandstone has become a sequence of interbedded sandstone and siltstone and as such would be indistinguishable from the Burralow Formation as seen west of the Webbs Creek-Mount Murwin anticline. Alternatively, the Burralow Formation could have thickened.

Between 12 and 13 the uniformity of the basal, probable Caley Formation, over this distance is in striking contrast to the problem in attempting to follow the Burralow Formation eastwards from Sections 4 to 14 and then on to 19. Some 12 sections were originally measured between 14 and 19 and it was most problematical correlating individual units between each section.

Chocolate claystone and siltstone, regarded as the most reliable horizons for correlation elsewhere in the basin, were found to be useless for this purpose within the area studied. They were not confined to readily correlated horizons as are the Bald Hill Claystone and Stanwell Park Claystone of the South Coast (Hanlon, Osborne and Raggatt, 1953), but occurred haphazardly throughout the entire stratigraphic section.

Basic Igneous Bodies

General

There are a number of occurrences of basic volcanics throughout the area, some being caps, representing flow remnants, others being volcanic necks. The term basalt is used, but in a wide sense to cover all dark fine grained basic volcanic rocks. The basalt is almost invariably fine grained, very dark blue to black in colour, and lacks phenocrysts of any kind. No form of metamorphism, either as baking due to heat or fracturing of the surrounding sediments, was found associated with the necks or caps.

Necks

The necks are more common west and north of the axes of the Mellong Syncline-Howes Valley Syncline. The number and size of these bodies increases towards the edge of the basin as is evident by the number and distribution recorded by Carne (1908) and Day (1961). Their position commonly coincides with the area from which the Hawkesbury Sandstone is absent. Between 33°00′S and 33°15′S, necks are absent within the area mapped, except for those west of the Mellong Syncline, but are scattered over the area south of 33°15′S.

The necks invariably weather faster than the surrounding sediments and are thus always found in depressions. Often no outcrops or even floaters were found, but when they were, the rocks in them were commonly found to be breccias with fragments of sediments, especially water worn pebbles. One exception is the large neck at (38807720) where a central body of large blocks of columnar basalt occurs. This is surrounded by a wide rim of dark brown soil, probably derived from surrounding breccia. Even when no outcrop can be found, the presence of cleared lush grassland and the occurrence of a dark brown rich loam which never occurs on the Triassic sandstone country, is a very good indication of the presence of basic volcanics.

One neck where brecciation occurs is at Clear Farm Hollow (36939298), and is revealed by a number of recent cuttings at the side of the Putty Road. Brecciation and inclusion of pieces of country rock including sediment and water worn pebbles, the latter being common in the conglomerate beds of the Narrabeen Group and Singleton Coal Measures, the susceptibility of the breccia to weathering and its extreme softness are all evident at this locality.

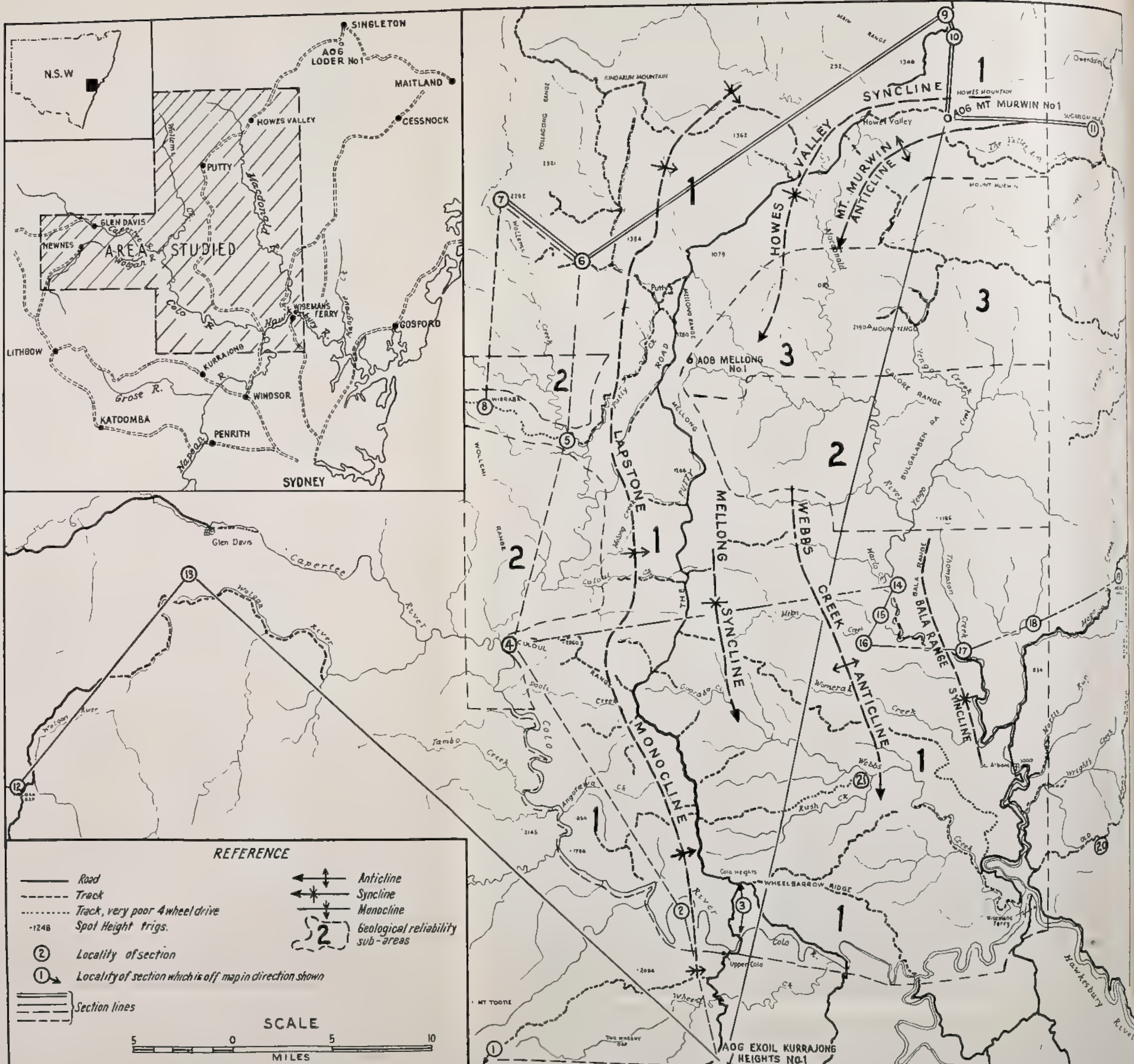


Fig. 2.—Major structures, section lines and localities.


Owendale
SUGARLOAF HILL
11
The Valley Arm Ck.
Werong Creek
Stockyard Ck
Yango Ck
Creek
19
MOGO HILL
18
Mogo
ROAD
834
Morris Run
NORTH
Wright's Creek
Albans
1000

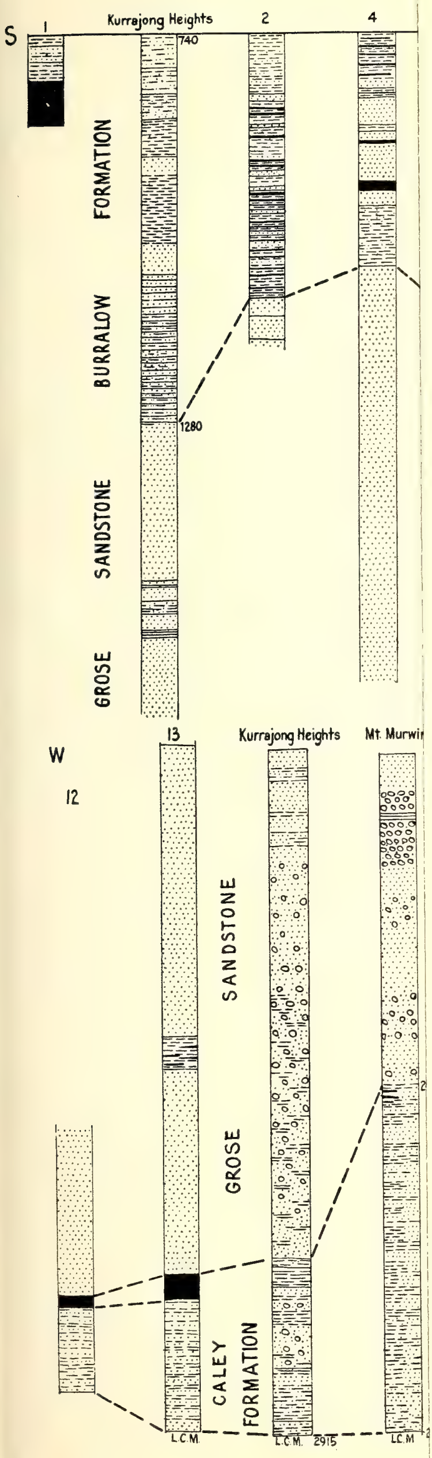


FIG. 3.—Localities and section

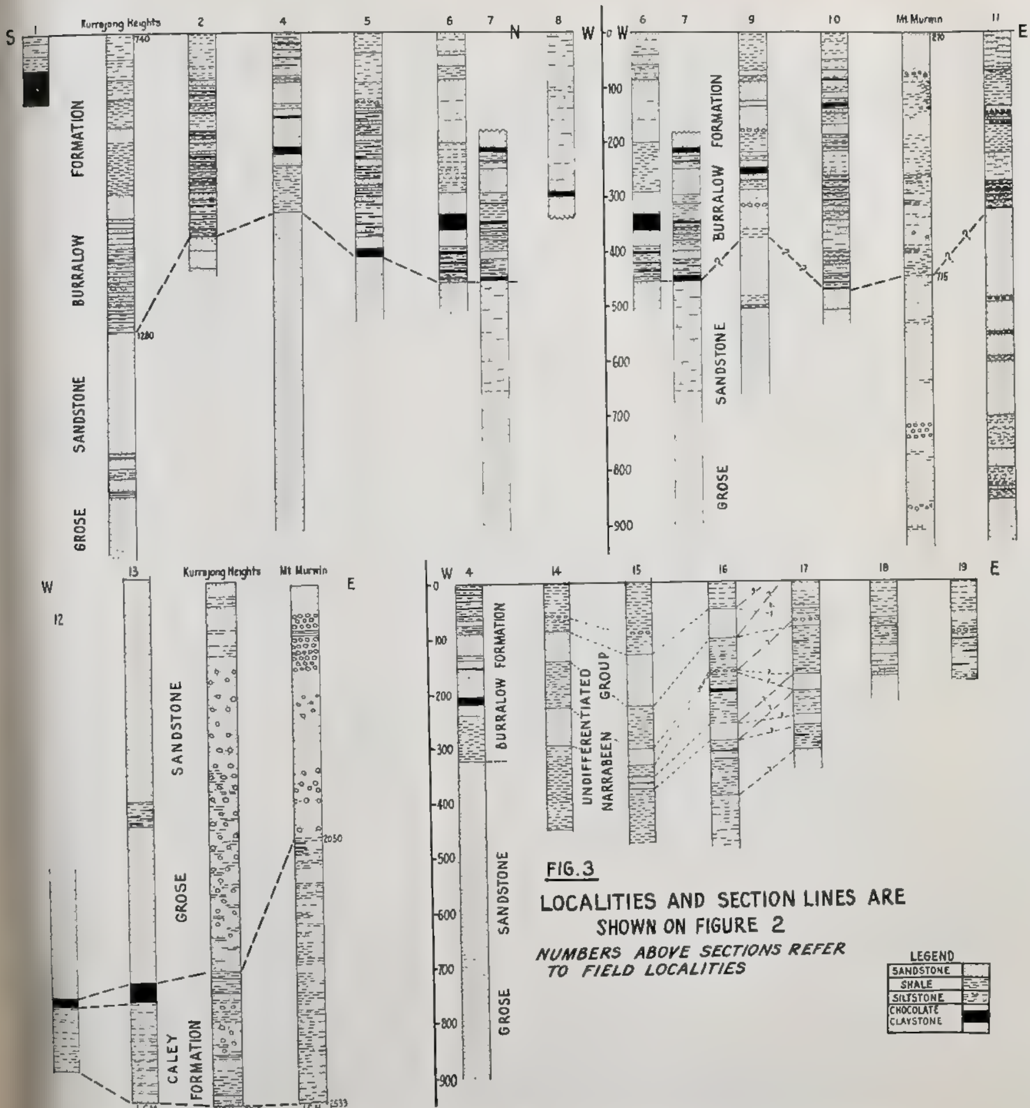
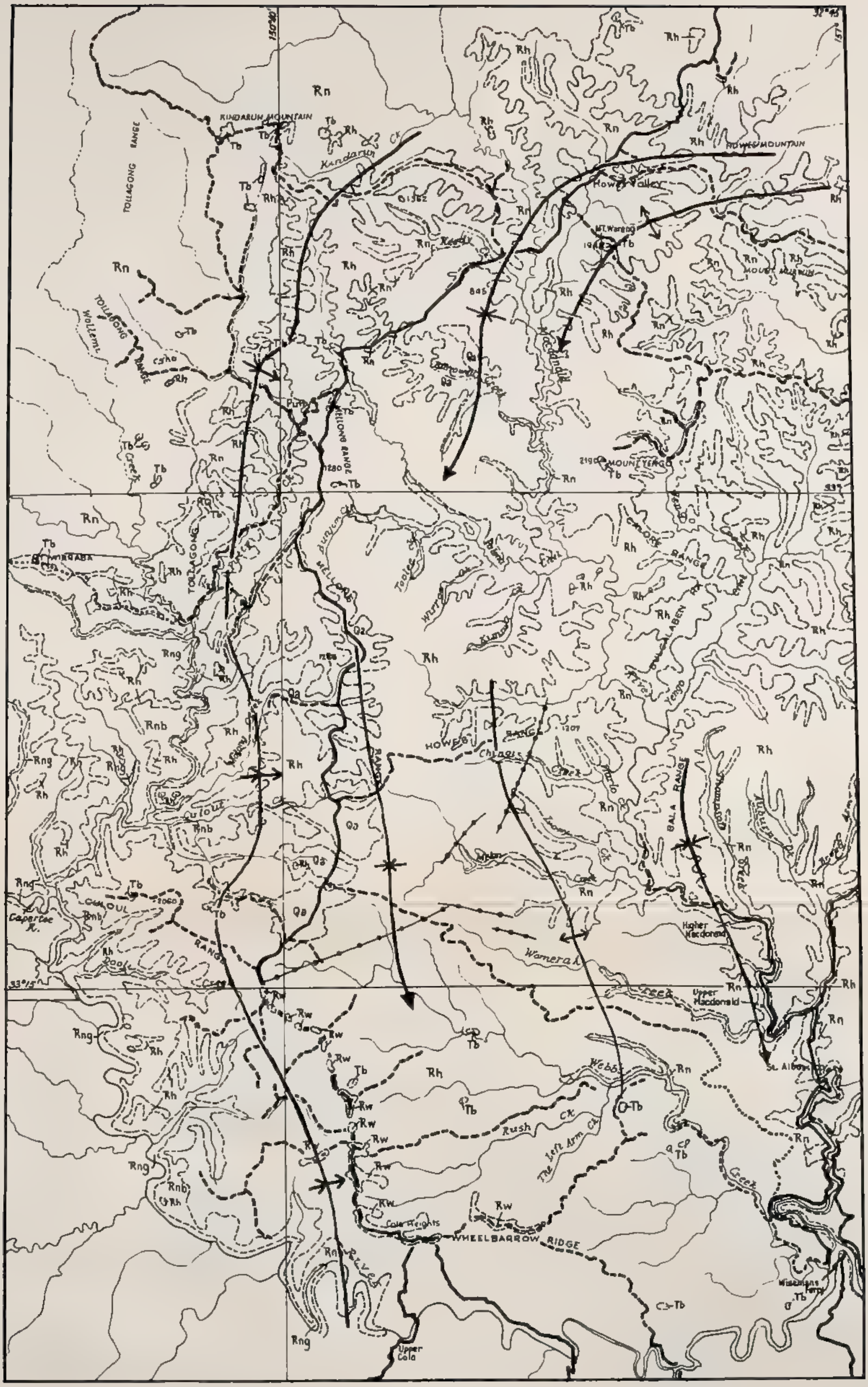


Fig. 3.—Localities and section lines are shown on Fig. 2. Numbers above sections refer to field localities.



LEGEND

CAINOZOIC		Qa	*Alluvium. Shown only where extensive*
POST TRIASSIC	Unnamed necks and caps	Tb	*Basalts, Volcanic Breccias*
TRIASSIC	Wianamatta Group	Rw	*Shales and flaggy sandstones*
	Hawkesbury Sandstone	Rh	*Sandstones, rare shales*
	Narrabeen Group Burralow Formation	Rnb	*Shale, chocolate claystone, Flaggy sandstone, sandstone*
	Grose Sandstone	Rng	*Sandstone, rare shale, chocolate claystone*
	Undifferentiated	Rn	*Shale, sandstone chocolate claystone.*

Possible dykes *Anticline, syncline, monocline*

SCALE 1:250.000

5 0 5 10 Miles

Fig. [illegible]. Geology of the Colo Putty district

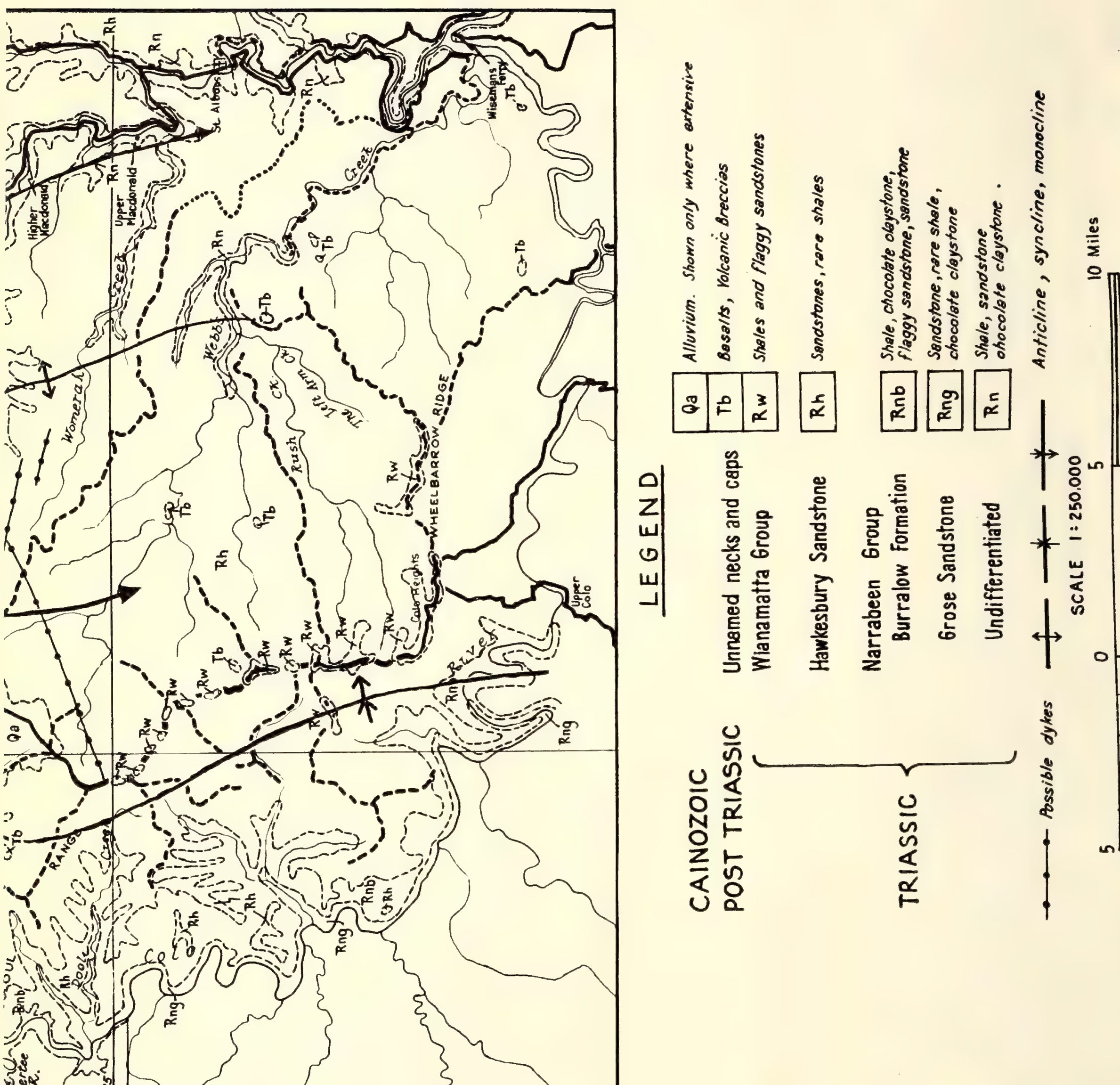


Fig. 4.—Geology of the Colo-Putty district.

Caps

These invariably occur on or near the crests of hills with large angular blocks of basalt always evident. Rare polygonal blocks suggest that, in the fresh basalt, columnar jointing was common. The caps are generally restricted to the west and north of the area, probably representing remnants of once more extensive flows. There is little reason to suppose that they are denuded intrusions, as nowhere are sediments found overlying them. None are known to occur in the area south of 33°15′S. The occurrences west of Six Brothers trig are the only ones known between latitudes 33°00′S and 33°15′S.

A number of basalt caps also occur north of 33°00′S. Generally their bases are obscured by scree making it difficult to estimate the relief of their bases.

Two exceptions are :—

(*a*) The occurrences west of Six Brothers trig (35658964) appear to have been laid down on an irregular surface. This is revealed by the more western of the two bodies where basalt occurs along a spur leading down from a knob of sandstone some 30 feet higher than the base of the basalt, which it also partially surrounds.
(*b*) The Mount Wirraba basalt (35158165) also appears to be laid down on an irregular surface, as its base is by no means flat. The hill is not all capped by basalt ; between the two occurrences is a knob of sandstone which is higher than the more western body.

Dykes

Possible dykes occur between 33°05′S and 33°15′S (see Fig. 4). Wide fissures with sheer walls, about 50 to 70 feet wide and several miles long, cleave through the continuous outcrop of the Hawkesbury Sandstone. Throughout the clefts only floaters of sandstone occur. Considering the paucity of outcrop in the necks, a dyke of this thickness would be expected to be so extensively weathered that it would not outcrop. These fissures could be faults in which shearing had so brecciated the sandstone that it fell to powder on exposure and so did not outcrop. If this were the case, why did shearing stop completely at the two sandstones which border the zone of no outcrop which exists to-day ? One would expect joints, minor faulting, or shearing to be evident in the sandstone at either side, or at least to cause an irregular weathering surface on the sandstone. Instead, two almost planar vertical walls occur.

Another dyke occurs on Mogo Hill (40839025) in the road cutting near the base of the Hawkesbury Sandstone. It is about one foot wide and completely kaolinised. Other dykes in a similar state occur around Howes Valley, but are only exposed in road cuttings. Narrow fissures with vertical walls occur in the sandstone at scattered localities along Wollemi Creek ; these may represent the sites of now completely weathered out dykes.

Peneplanation and its Relation to Bases of Caps

Comparing the altitude of the base of the basalt flows on the various caps, it is seen that Mount Yengo, Poppong, Wareng and Warrawolong (42729157) all have the bases of their basalt caps at roughly the same level of 1800 feet. The Culoul Range caps further south are at 1900 feet, while due north Kindarun Mountain, west of Mount Wareng, has its basalt base at 2200 to 2300 feet ; Mount Wirraba, west of Kindarun, has its basalt base at 2400 feet ; Gospers Mountain further west has its basalt base at 2600 feet.

It can be seen that these levels coincide with a surface which becomes progressively higher westwards and is higher than that of the supposed Tertiary peneplain. The Tertiary peneplain is supposed to be represented by a surface joining the highest points of the topography. The higher basalt surface is clearly above this and possibly corresponds to an earlier stage in the development of the peneplain. The additional caps, such as Box Bump (34038306), Green Hill (37298396) and Putty trig (36388305) are smaller in extent and at a much lower level, possibly representing a later stage when dissection of the Tertiary peneplain was occurring.

The Putty trig basalt, in particular, is well below the surface of the other basalts and may represent an even later phase in vulcanism, following erosion of the "higher" basalts and of the Tertiary peneplain surface.

Age

The age of these bodies has generally been regarded as Tertiary. Recent work on the age of the Prospect intrusion, based on radioactive dating and supplemented by paleomagnetic work (Manwaring, 1963), has established it as Middle Jurassic. Paleomagnetic work on the Peats Ridge neck indicates a probable Tertiary age (Manwaring, 1963).

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Discussions with Mr. J. Stuntz throughout the field work and with Mr. K. Bradley of A.O.G., in the later stages of the field work helped to mould the ideas leading to this work.

Discussions also took place from time to time with various members of the staff of the University of Sydney, particularly Dr. A. J. T. Wright and my supervisor Dr. T. B. H. Jenkins.

Criticism of the manuscript at various stages by Drs. T. B. H. Jenkins, K. A. W. Crook and C. T. McElroy were of considerable assistance.

Finally I would like to thank my mother for her encouragement throughout this study and for typing the whole of this paper.

Geological Reliability

The geological reliability of the sub areas shown on Fig. 2 is as follows:

Area 1.—The whole of this area has been mapped in the field by the author, except the extreme west and north west between latitudes 34°45′S and 33°00′S. Reconnaissance work was carried out to ensure that only Narrabeen Group sediments occurred throughout this area.

Area 2.—No field work has been done in this area. With the guidance of field work to the south and west the boundaries have been determined by air photo interpretation.

The geology of these areas has been reduced from maps at a scale of 1 : 63360 and 1 : 50,000. Thus, the boundaries shown on Fig. 4 are regarded as very reliable.

Area 3.—The air photos being used did not cover this area and no field work was carried out. The boundaries shown were extrapolated from the north, west and south of the area. However, on the scale of Fig. 4 the boundaries are thought to be reliable.

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Report of the Council for the Year Ended 31st March, 1967

Presented at the Annual and General Monthly Meeting of the Society held 5th April, 1967, in accordance with Rule XXVI.

At the end of the period under review the composition of the *membership* was 352 members, 21 associate members and 8 honorary members ; 17 new members were elected. Four members and two associate members resigned ; the names of three members were removed from the list of members in accordance with Rule XVIII.

It is with extreme regret that we announce the *loss by death* of :

Sir Neil Hamilton Fairley (elected to Honorary Membership, 1952),

Thelma I. Christie (elected 1953),

Edward J. Kenny (elected 1924),

Stephen L. Leach (elected 1936),

Henry J. Meldrum (elected 1912),

Archibald B. B. Ranclaud (elected 1919),

Arthur Spencer Watts (elected 1919).

Centenary. To commemorate the 100th Anniversary of the Grant of Royal Charter by H.M. Queen Victoria, the following celebrations were held :

8th June : The Centenary Dinner under the Patronage of His Excellency the Governor of New South Wales, Sir Roden Cutler, V.C., K.C.M.G., O.B.E., in the Sapphire Room, Australia Hotel, the attendance being 85 (see " Journal and Proceedings ", vol. 100, pp. 1-8).

28th October : The Centenary Address entitled " 1866, the Challenge *to* Science ; 1966, the Challenge *of* Science ", was held in the Hall of Science House, and was delivered by Professor A. P. Elkin, C.M.G., M.A., Ph.D. The Address was preceded by a Buffet Meal held in the Edgeworth David Room.

1st November to 18th December : The Centenary Exhibition was held in the Australian Museum, College Street, Sydney. Exhibits were contributed by Sydney Observatory ; Institute of Medical Research, Royal North Shore Hospital ; National Standards Laboratory ; Australian Atomic Energy Commission and the Museum of Applied Arts and Sciences. Several cases contained exhibits in connection with the work of K. E. Bullen, T. W. E. David, L. Hargrave, A. Liversidge, J. H. Maiden, H. G. Smith; all distinguished members of the Society. Also, an exhibit emphasizing the range of material in the Society's library and in the " Journal and Proceedings " was displayed.

Eight monthly meetings were held. The abstracts of all addresses have been printed on the notice paper. The proceedings of these will appear later in the issue of the " Journal and Proceedings ". The members of the Council wish to express their sincere thanks and appreciation to the eight speakers who contributed to the success of these meetings, the average attendance being 45.

The *Annual Social Function* was held on 30th March at the Sydney University Staff Club and was attended by 55 members and guests.

The Council has approved the following awards :

The *Clarke Medal* for 1967 to Professor S. Smith-White, D.Sc.Agr., F.A.A., School of Biological Sciences, University of Sydney.

The *Society's Medal* for 1966 to Mr. H. A. J. Donegan, of the Mining Museum, Sydney.

The *James Cook Medal* for 1966 to Sir William Hudson, K.B.E., F.R.S., of the Snowy Mountains Hydro Electric Authority, Cooma.

The *Edgeworth David Medal* for 1966 to Dr. R. I. Tanner, Department of Engineering, Brown University, Providence, U.S.A.

The *Archibald D. Ollé Prize* to Dr. R. A. Binns, Department of Geology, The University of New England.

The *Liversidge Research Lecture* for 1966, entitled " Organic Metals ?", was delivered by Professor L. E. Lyons, Ph.D., Department of Physical Chemistry, University of Queensland, on 12th July (see " Journal and Proceedings ", vol. 101, pp. 1-9).

The Society has again received a *grant* from the Government of New South Wales, the amount being $1,500. The Government's interest in the work of the Society is much appreciated.

The Society's *financial statement* shows a deficit of $2,133.11.

The *New England Branch* of the Society met 3 times during the year and the Proceedings of the Branch follow this report.

The President represented the Society at the Commemoration of the Landing of Captain James Cook at Kurnell ; attended the Garden Party held at Government House in Honour of the Birthday of Her Majesty the Queen ; the State Reception in the Art Gallery of New South Wales held to welcome the President of the U.S.A. and Mrs Johnson ; and, during the visit of His Royal Highness the Duke of Edinburgh, was a guest at a State Luncheon ; and was present at the Australian Function on the occasion of the official opening of the South East Asia Commonwealth Cable by Her Majesty the Queen.

The President attended the Annual Meeting of the Board of Visitors of the Sydney Observatory.

We congratulate Professor A. P. Elkin, on the award of the C.M.G.; Dr. H. J. Hynes, on the award of a Fellowship of the Australian Institute of Agricultural Science ; Mr. J. M. Rayner, on the award of the O.B.E.; and Dr. Alice Whitley, on the award of the M.B.E.

The Society's representatives on *Science House Management Committee* were Mr. H. F. Conaghan and Mr. W. H. G. Poggendorff.

Publications. Two parts of volume 98, volume 99 which was the W. R. Browne volume and volume 100, part 1, have been published during the year.

The *Centenary Volume,* which will be a special publication, is planned for the coming year.

Council held 11 ordinary meetings and the attendance was as follows : Prof. A. H. Voisey 11 ; Dr. A. A. Day 7 ; Prof. R. J. W. Le Fevre 6 ; Mr. H. H. G. McKern 10 ; Mr. W. H. G. Poggendorff 4 ; Mr. J. L. Griffith

10; Dr. A. Reichel 8; Mr. H. F. Conaghan 9; Mr. R. A. Burg 6; Mr. J. C. Cameron 9; Mr. A. F. A. Harper 6; Prof. A. Keane 3 (absent-on-leave 3); Mr. T. E. Kitamura 10; Mrs. M. Krysko v. Tryst (appointed 30/8/1966) 3; Dr. D. B. Lindsay (New England Branch representative as from November, 1966) 0; Mr. J. W. G. Neuhaus 8; Mr. J. P. Pollard 7; Mr. W. H. Robertson 6; A/Prof. R. L. Stanton (absent-on-leave 8 and not eligible for the remainder of the session as the New England Branch had nominated Dr. D. B. Lindsay as its representative commencing the current session of the Branch).

Council has prepared *a new set of Rules and By-laws* for presentation to the members of the Society.

The Library—Periodicals were received by exchange from 390 societies and institutions. The amount of $386.33 was expended on the purchase of 11 periodicals and book-binding. This expense was partly defrayed by an amount of $190.00 realized from Company Membership subscriptions. Repairs to and binding of the more rare sets of periodicals continues, costing $242.09 during the last year.

Among the institutions which made use of the library through the inter-library loan scheme were:

N.S.W. Govt. Depts.—Dept. of Agriculture, Hawkesbury Agricultural College, Electricity Commission of N.S.W., Forestry Commission, Dept. of Mines, National Herbarium, Dept. of Public Health, Railway Dept., Soil Conservation, Water Conservation & Irrigation Commission, Division of Wood Technology.

Commonwealth Govt. Depts.—Australian Atomic Energy Commission, Bureau of Mineral Resources, Geology & Geophysics, C.S.I.R.O. Divisions: Armidale Pastoral Research Station; Canberra Laboratories; Animal Physiology, Prospect; Chemical Research Laboratories, Melbourne; Coal Research, Ryde; Fisheries and Oceanography, Cronulla; National Standards Laboratory, Sydney; Textile Physics, Ryde; Wildlife, Canberra.

Universities and Colleges—Adelaide University, Australian National University, Sydney University, Canterbury, N.Z. University, Flinders University of South Australia, Melbourne University, Monash University, Mt. Stromlo Observatory, New England University, University of New South Wales, Queensland University, School of Public Health and Tropical Medicine, University of Tasmania, University College of Townsville, University of Western Australia, Wollongong University College.

Companies—Australian Cream of Tartar Ltd., A.W.A. Ltd., Australian Iron and Steel Co. Ltd., Australian Glass Manufacturers Ltd., B.H.P. Co. Ltd., Commonwealth Industrial Gases, C.S.R. Co. Ltd. Head Office, James Hardie & Co.. Ltd., I.C.I. Ltd., Lysaght Ltd., McDonald Constructions, Sulphide Corp. Pty. Ltd., S.T.C. Ltd., Unilever, Union Carbide Ltd.

Research Institutes—Bread Research Institute, C.S.R. Research Laboratories, Government Chemical Laboratories, Royal North Shore Hospital, St. Vincent's Hospital, Sydney Hospital.

Museum—Australian Museum.

Miscellaneous—Dept. of Agriculture, Stock and Fisheries, Papua; Institution of Engineers, Aust.; Linnean Society of N.S.W.; Newcastle City Council; Dept. of Primary Industries, Brisbane; W.E.A., Sydney.

Our *Assistant Secretary*, Miss M. Ogle, retired on 31st December, 1966 after a period of 20 years with the Society. The Council wishes to express its appreciation of her excellent and untiring services during this record period. Miss Ogle will be continuing for some time on a part time basis.

J. L. Griffith,
Honorary Secretary.

5th April, 1967.

Abstract of Proceedings

6th April, 1966

The ninety-ninth Annual and eight hundred and ninth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Dr. Alan A. Day, was in the chair. There were present 55 members and friends.

Donald Westland Emerson was elected a member of the Society.

The Annual Report of the Council and the Financial Statement were presented and adopted.

The following awards of the Society were announced :

The Society's Medal for 1965 : Dr. Francis Lions.

The Clarke Medal for 1966 : Prof. Dorothy Hill, F.R.S., F.A.A.

The Walter Burfitt Prize for 1965 : Dr. Charles A. Fleming, O.B.E.

The James Cook Medal for 1965 : Dr. John T. Gunther, C.M.G., O.B.E.

The Edgeworth David Medal for 1965 : Prof. John L. Dillon.

Dr. W. R. Browne was presented with a specially bound copy of Volume 99 of the " Journal and Proceedings ", published as a tribute to Dr. Browne's long and distinguished service to Australian science.

Office-Bearers for 1966-67 were elected as follows :

President : A. H. Voisey, D.Sc.

Vice-Presidents : A. A. Day, Ph.D., R. J. W. Le Fevre, D.Sc., F.R.S., F.A.A., H. H. G. McKern, M.Sc., W. H. G. Poggendorff, B.Sc.Agr.

Hon. Secretaries : J. L. Griffith, B.A., M.Sc., A. Reichel, Ph.D.

Hon. Treasurer : H. F. Conaghan, M.Sc.

Members of Council : R. A. Burg, A.S.T.C., J. C. Cameron, M.A., B.Sc., D.I.C., A. F. A. Harper, M.Sc., A. Keane, Ph.D., T. E. Kitamura, B.A., B.Sc.Agr., J. Middlehurst, M.Sc., J. W. G. Neuhaus, A.S.T.C., J. P. Pollard, Dip.App.Chem., W. H. Robertson, B.Sc., R. L. Stanton, Ph.D.

Messrs. Horley & Horley were re-elected auditors to the Society for 1966-67.

The retiring President, Dr. Alan A. Day, delivered his Presidential Address entitled " A Historical Outline of the Development of Geophysics in Australia ".

The following papers were read by title only :

" Petrography of some Permian Sediments from the Lower Hunter Valley of New South Wales ", by J. D. Hamilton.

" The Big Hole near Braidwood, N.S.W.", by J. N. Jennings.

" On Lepidipteris Madagascariensis Carpentier (Peltaspermaceae) ", by John A. Townrow.

" Precise Observations of Minor Planets at Sydney Observatory during 1963 and 1964 ", by W. H. Robertson.

At the conclusion of the Presidential Address the retiring President welcomed Professor Voisey to the Presidential Chair.

4th May, 1966

The eight hundred and tenth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Professor A. H. Voisey, was in the chair. There were present 44 members and visitors.

The following were elected members of the Society : Norman Thomas Feather, Petro Majstrenko and John Herbert Rattigan.

An address entitled " Oral Contraceptives from the Medical Viewpoint " was delivered by Professor H. M. Carey, of the School of Obstetrics and Gynaecology, University of New South Wales.

It was announced that as the Centenary Dinner was being held on 8th June, there would be no General Monthly Meeting held during that month.

No meeting was held during the month of June, 1966.

6th July, 1966

The eight hundred and eleventh General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Professor A. H. Voisey, was in the chair. There were present 32 members and visitors.

The following were elected members of the Society : Roger John Henderson and Derek Barber Lindsay.

The following papers were read by title only : " Plant Microfossils from a Shale within the Wollar Sandstone, N.S.W.", by R. J. Helby ; " Time Spent by Neutrons inside a Narrow Resonance ", by C. A. Wilkins ; " Minor Planets Observed at Sydney Observatory During 1965 ", by W. H. Robertson.

An address entitled " World Wide Water Problems ", was delivered by Mr. R. J. Griffin, of the Hydrology Division, Geological Survey, Department of Mines, N.S.W.

3rd August, 1966

The eight hundred and twelfth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Professor A. H. Voisey, was in the chair. There were present 25 members and visitors.

Robin James Helby was elected a member of the Society.

An address entitled " Physics, Chemistry and Biology of Some Long Molecules " was delivered by Professor P. Mason, School of Mathematics and Physics, Macquarie University.

7th September, 1966

The eight hundred and thirteenth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Professor A. H. Voisey, was in the chair. There were present 64 members and visitors.

The following were elected members of the Society : Barry Deane Webby and Helmut Wopfner.

Films : " The Dead Sea Scrolls " and " The Hebrew University " were screened by courtesy of the New South Wales Friends of the Hebrew University and were introduced by Mr. A. D. Crown, President of the New South Wales Friends of the Hebrew University and Lecturer in Semitic Studies at the University of Sydney.

5th October, 1966

The eight hundred and fourteenth General Monthly Meeting was held in the Hall of Science House, Sydney, at 7.45 p.m.

The President, Professor A. H. Voisey, was in the chair. There were present 25 members and visitors.

The following were elected members of the Society : Ian Douglas Blayden, Neil Neville Gow, Krishna Kumar Sappal and Stirling Edward Shaw.

The following papers were read by title only : " The Gravity Terms in the Water Entry Problem ", by A. H. Low ; " Occultations Observed at Sydney Observatory During 1964-65 ", by K. P. Sims.

An address entitled " What is the Quality of a Musical Note ?" was delivered by Mr. R. S. Caddy, Vice-Chancellor's Division, the University of New South Wales.

2nd November, 1966

The eight hundred and fifteenth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Professor A. H. Voisey, was in the chair. There were present 87 members and visitors.

The following were elected members of the Society : Charles Phillip Gabel, George Studley Gibbons and Geoffrey Harold Roper.

The following paper was read by title only : " The Balickera Section of the Carboniferous Kuttung Facies, New South Wales ", by J. H. Rattigan.

An address entitled " Offshore Exploration " was delivered by Mr. D. C. Edwards, of ESSO Exploration Australia, Inc., Sydney.

7th December, 1966

The eight hundred and sixteenth General Monthly Meeting was held in the Hall of Science House, Sydney, at 7.45 p.m.

The President, Professor A. H. Voisey, was in the chair. There were present 30 members and visitors.

George Arthur Peterson was elected a member of the Society.

An address entitled " A Pattern for a University in New Guinea " was delivered by Dr. John T. Gunther, C.M.G., O.B.E., Vice-Chancellor, University of Papua and New Guinea, Port Moresby.

Members of the Society, April, 1967

A list of the members of the Society up to 1st April, 1966 is included in Volume 100.

During the year ended 31st March, 1967 the following were elected to membership of the Society :

BLAYDEN, Ian Douglas, B.Sc.(Hons.), Geologist, 13 Murrakin Street, Kahibah, N.S.W.

EMERSON, Donald Westland, M.Sc., B.E.(App.Geol.), Department of Geology and Geophysics, The University of Sydney.

FEATHER, Norman Thomas, B.A., M.A., Ph.D., Dip.Ed., Associate Professor of Psychology, The University of New England.

GABEL, Charles Phillip, Forester, 59 Abingdon Road, Roseville.

GIBBONS, George Studley, M.Sc., 75 Nicholson Street, St. Leonards.

GOW, Neil Neville, B.Sc.(Hons.), C.R.A. Exploration, G.P.O. Box 384D, Melbourne.

HELBY, Robin James, M.Sc., 344 Malton Road, North Epping.

HENDERSON, Roger John, B.Sc.(Hons.), Department of Geology and Geophysics, The University of Sydney.

LINDSAY, Derek Barber, B.Sc., M.A., D.Phil.(Oxford), Department of Biochemistry and Nutrition, The University of New England, Armidale.

MAJSTRENKO, Petro, M.Sc.(Copenhagen), Lecturer in Mathematics, The University of New England, Armidale.

PETERSON, George Arthur, B.Sc., B.E., 55 Roseville Avenue, Roseville.

RATTIGAN, John Herbert, Ph.D., M.Sc., 17 Mills Street, Warners Bay, N.S.W.

ROPER, Geoffrey Harold, Ph.D., M.Sc., Associate Professor of Chemical Engineering, The University of New South Wales, Kensington.

SAPPAL, Krishna Kumar, M.Sc., Geologist, Department of Geology, Nagpur University, Nagpur, India.

SHAW, Stirling Edward, B.Sc.(Hons.), Ph.D., F.G.A.A., School of Earth Sciences, Macquarie University, Eastwood.

WEBBY, Barry Deane, Ph.D., M.Sc., Department of Geology and Geophysics, The University of Sydney.

WOPFNER, Helmut, Ph.D., Supervising Geologist, South Australian Geological Survey, S.A. Department of Mines, Box 38, Rundle Street, P.O., Adelaide, S.A.

During the same period resignations were received from the following :

Burns, (Mrs.) Susan Mary (Associate).
Findler, Nicholas Victor.
Gow, Neil Neville (resigned as an associate to transfer to full membership).
Jones, (Mrs.) Robin.
Murray, Patrick Desmond Fitzgerald.
Wilson, Peter Robert.

and the following names were removed from the list of members under Rule XVIII :

Hawkins, Cedric Arthur.
Lang, Thomas Arthur.
Lewis, Philip Ronald.

Financial Statement

The Honorary Treasurer's Report

The Society this year recorded a deficit of $2,133.11. The major factors contributing to this deficit were a loss of $462.27 on the Centenary Celebrations, increases in expenditure of $172.00 for library purchases, $104.00 for postages, $845.00 for printing and $517.00 for salaries together with an overall decrease of $159.00 in income.

In addition to the subscriptions to journals and periodicals being increased, a number of rare and valuable books belonging to the Society were repaired resulting in an increase in the library purchase expenditure.

The increased expenditure on printing was due to the increased activity in publication. Volume 98, parts 3 and 4, Volume 99 and Volume 100, part 1, of the Society's "Journal and Proceedings" were published during the year.

The expenditure on salaries as shown in the balance sheet includes an amount of $604.89 for long service leave payment.

Company membership subscriptions amounting to $190.00 are not shown as income but are credited to library purchases, for which these subscriptions are intended.

An application to the Minister for Education and Science for an increase in the Government Grant to the Society was refused but a grant of $4,000.00 towards the cost of producing the Centenary publication was approved.

H. F. CONAGHAN,
Honorary Treasurer.

5th April, 1967.

THE ROYAL SOCIETY OF NEW SOUTH WALES

BALANCE SHEET AS AT 28th FEBRUARY, 1967

LIABILITIES

1966 $		$	$
384	Accrued Expenses		—
36	Subscriptions Paid in Advance		91.40
153	Life Members' Subscriptions—Amount carried forward..		140.70
	Trust Funds (detailed below)—		
	Clarke Memorial	4,270.32	
	Walter Burfitt Prize	2,426.43	
	Liversidge Bequest	1,425.04	
	Ollé Bequest	581.26	
8,570			8,703.05
60,030	Accumulated Funds		57,870.28
6,376	Library Reserve Account		7,520.02
502	Employees' Long Service Leave Fund Provision.. ..		—
	Contingent Liability (in connection with Perpetual Lease)		
$76,051			**$74,325.45**

ASSETS

4,218	Cash at Bank and in Hand		1,764.76
	Investments—		
	Commonwealth Bonds and Inscribed Stock—		
	At Face Value—held for :		
	Clarke Memorial Fund	3,600.00	
	Walter Burfitt Prize Fund	2,000.00	
	Liversidge Bequest	1,400.00	
	General Purposes	9,680.00	
16,680			16,680.00
502	Fixed Deposit—Long Service Leave Fund		518.40
	Debtors for Subscriptions	132.85	
	Less : Reserve for Bad Debts	132.85	
—			—
29,670	Science House—One-third Capital Cost		30,470.43
13,600	Library—At Valuation		13,600.00
9,600	Library Investment—Special Bonds		9,600.00
	Furniture and Office Equipment—At Cost, *less*		
1,755	Depreciation		1,667.06
24	Pictures—At Cost, *less* Depreciation		22.80
2	Lantern—At Cost, *less* Depreciation		2.00
$76,051			**$74,325.45**

TRUST FUNDS

	Clarke Memorial $	Walter Burfitt Prize $	Liversidge Bequest $	Ollé Bequest $
Capital at 28th February, 1967	3,600.00	2,000.00	1,400.00	—
Revenue—				
Balance at 10th February, 1966 ..	546.01	471.52	56.33	496.76
Income for Period	190.56	105.71	74.71	84.50
	736.57	577.23	131.04	581.26
Less : Expenditure	66.25	150.80	106.00	—
Balance at 28th February, 1967 ..	$670.32	$426.43	$25.04	$581.26

ACCUMULATED FUNDS

	$	$
Balance at 10th February, 1966	60,029.63	
Add—		
Transfer Salary Adjustment	0.10	
Reserve for Bad Debts	117.05	
		60,146.78
Less :		
Transfer Salary Adjustment	0.10	
Transfer for Long Service Leave Fund..	86.59	
Subscriptions Written Off	56.70	
Deficit for the Period	2,133.11	
		2,276.50
		$57,870.28

Auditors' Report

The above Balance Sheet has been prepared from the Books of Account, Accounts and Vouchers of The Royal Society of New South Wales, and is a correct statement of the position of the Society's affairs on 28th February, 1967, as disclosed thereby. We have satisfied ourselves that the Society's Commonwealth Bonds and Inscribed Stock are properly held and registered.

HORLEY & HORLEY
Chartered Accountants.
Registered under the Public Accountants
Registration Act 1945, as amended.

65 York Street,
Sydney.
23rd March, 1967.

(Sgd.) H. F. CONAGHAN,
Honorary Treasurer.

INCOME AND EXPENDITURE ACCOUNT

10th FEBRUARY, 1966, to 28th FEBRUARY, 1967

1966				
$				$
16	Advertising			34.66
54	Annual Social			50.12
76	Audit			76.00
50	Branches of the Society			50.00
—	Centenary Celebrations			402.27
316	Cleaning			327.50
94	Depreciation			88.94
80	Electricity			75.44
27	Entertainment			9.62
85	Insurance			74.80
—	Legal Expenses			30.00
266	Library Purchases			438.42
526	Miscellaneous			450.31
213	Postages and Telegrams			317.57
	Printing—Journal—			
	Vol. 98, Part 3—Vol. 100, Part 1	$4,402.08		
	Binding	105.00		
	Reprints	1,325.98		
	Postages	193.34		
	Refund—Sale of Back Numbers	5.25		
	Fare—*re* Vol. 99	2.00		
			6,033.65	
	Less :			
	Sale of Reprints	2,033.40		
	Subscriptions to Journal	849.82		
	Sale of Back Numbers	211.94		
	Refund Postages	42.15		
	Sale of Block	20.00		
	Transfer Printing of Clarke Memorial Lecture	65.45		
	Accrued Expenses	139.72		
			3,362.48	
1,826				2,671.17
80	Printing—General			23.88
2,425	Rent—Science House Management			2,454.25
12	Repairs			15.34
2,812	Salaries			3,329.50
48	Storage Expenses			—
81	Telephone			87.14
$9,087				$11,006.93

1966		
$		$
1,920	Membership Subscriptions	1,948.80
12	Proportion of Life Members' Subscriptions	12.60
1,500	Government Subsidy	1,500.00
4,188	Science House Management—Share of Surplus	4,876.57
650	Interest on General Investments	525.85
241	Donations	10.00
190	Company Membership	—
14	Sundry Receipts	—
372	Deficit for the Period	2,133.11
$9,087		$11,006.93

Section of Geology

CHAIRMAN : G. S. Gibbons. HON. SECRETARY : (Mrs.) M. Krysko v. Tryst.

Abstract of Proceedings, 1966

Five meetings were held during the year, the average attendance being about 12 members and visitors.

MARCH 18th (Annual Meeting) : Election of Office Bearers was postponed until the next meeting.

Address by Dr. G. H. Taylor : " Recent Advances in Coal Petrology ". Dr. Taylor drew attention to the fact that many minerals occur in different coals. The most common of these are the layer silicates (chiefly clays), quartz and chalcedony, sulphides (pyrite, marcasite, sphalerite), carbonates (calcite, ankerite, siderite) and sulphates (barite, gypsum). As well, minerals such as apatite may be locally abundant. The modes of occurrence and associations of many of these in Australian coals were illustrated and discussed. Attention was drawn to the similarity of petrifaction structures formed as a result of replacements of plant tissue by very different mineral species. Some of the practical consequences of inorganic matter in coal during its combustion and carbonization were referred to.

MAY 20th : Election of Office Bearers : Chairman : Mr. D. S. Bridges; Hon. Secretary: Mrs. M. Krysko v. Tryst.

(1) Address by Professor A. H. Voisey : " Some observations on the Geology of the United States and Mexico."

Using colour slides, Professor A. H. Voisey summarized the geology of the United States and Mexico emphasizing the influence of the main geosynclinal belts and cratonic blocks on the thicknesses and structures of the sedimentary sequences. The widespread occurrence of limestone over the cratonic areas and development of Florida was contrasted with the rise of greywackes and turbidites contributing to the development of Puerto Rico and ultimately to portions of the continents.

(2) Notes and Exhibits : Mr. E. Lassak exhibited phosphatic rocks from the Sydney area and reported as follows :

a. Garie Beach—Thelma Head Area :

Three types of rock have been noticed :

1. green gray phosphoritic nodules and pebbles in sandstone (13% P_2O_5).
2. bands of calcitic phosphorite in sandstone (8% P_2O_5).
3. white, green and yellowish nodules of a phosphatic clay in sandstone.

All these samples occurred in the Bulgo sandstone (below Bald Hill Claystone)—Narrabeen Group.

b. Mona Vale—headland north of Mona Vale Beach : bands and nodules of a dark sideritic phosphorite in sandstone. The phosphatic rocks occur in the Gosford Formation (above Collaroy Claystone)—Narrabeen Group.

JULY 15th : Notes and Exhibits accompanied by short addresses :

a. Professor L. J. Lawrence exhibited specimens and spoke on some mesostructures and macrostructures in orebodies in high grade metamorphites. In such orebodies, where ore and country rock have been metamorphosed at high grade, masses of sulphide-silicate material apparently " intrusive " into the recrystallized orebody as a whole exhibit textures similar to pegmatites. Other intrusives consist of " reef quartz " with sulphides and still others comprise traditionally low temperature minerals such as zeolites, chalcedony, amethyst etc. Professor Lawrence considered these various facies to be the products of a differentiated anatexis (or partial melt) of pre-existing ore. This belief is supported by phase studies in the system Fe-Zn-Pb-S.

b. Dr. Koch, in a short paper entitled " Mineralogical and Gem Treasures of Europe", reported on and illustrated by colour slides, outstanding mineralogical and gemstone specimens seen and in part examined by him, in public and private collections of seven European countries.

c. Mr. L. Hamilton exhibited specimens of :

1. Devonian ignimbrites from central N.S.W. He pointed out that many of the Silurian-Devonian rocks mapped as rhyolites in N.S.W. are actually ignimbrites.

2. A " Fossil fumerole ", or pyroclastic vein in a Carboniferous ignimbrite from near Seaham, N.S.W. This was compared with similar structures in the Waitahina Ignimbrite in N.Z.

3. Slices of bore cores of the Matahina Ignimbrite from N.Z. arranged in order of depth to show the wide range of textural variations found in ignimbrite cooling units.

4. Slightly pumiceous rhyolite from the flank of Tarawera Volcano (N.Z.) and forms of the basalt involved in the 1888 eruption of the volcano.

SEPTEMBER 16th : Address by Dr. A. D. Albani : " Courses in Geology at Italian Universities and the Organization of Geology in Italy."

Dr. Albani gave a brief account of university education in geological sciences in Italy and introduced the subject by a general review of the primary and secondary school education with special emphasis on the different type of secondary schools (classical and otherwise).

A detailed analysis of the matriculation certificate and its difficulties preceded the description of the University courses (i.e. compulsory as well as optional courses) including class room hours, text books generally used, examination systems and extent of independent studies expected of the student.

The analysis of the university courses was concluded with the description of the Doctoral Degree system and including the associated three theses.

The very few governmental and private enterprises in the field of geology were then examined in the light of the growing demand for positions for geologists.

NOVEMBER 18th :

a. Dr. Golding exhibited specimens of variolitic spilite and derived metasomaties from Mt. Lightning, in the Coolac Serpentine Belt, N.S.W. The spilite appeared to be of post-peridotite age and its micro-texture indicated that it had cooled rapidly under little cover. The altered rocks included prehnitized and epidotized types, substantially monomineralic prehnite rocks and zoisite rock and a garnet-chlorite rock.

b. Mr. G. Gibbons pointed out that an unusual feature was exposed in the Minchinbury Farm diatreme (Fitzpatrick's quarry) in 1959. This was an irregular sandstone dyke, of which three successive exposures in the quarry wall were sketched at the time.

The sandstone consisted almost entirely of quartz grains of medium size, cemented by calcite. Field relations indicate that the sand must have intruded into its present position in some way, presumably by entrainment of the grains in a moving fluid. The origin of the grains was by disaggregation of sandstone, possibly from the Wianamatta Group nearby.

The suggestion by A/Prof. Vallance that the calcite cement might be a post-emplacement replacement of clays or other matrix would support an origin from the polymictic Wianamatta sandstones ; and the former presence of finer material would certainly make fluidization a more likely process of emplacement.

c. Mr. L. Hamilton drew attention to the unusual shapes of the igneous fragments in the breccia pipes near Sydney. The irregular shapes of many of the fragments suggest they were plastic at the time the breccia was formed. These shapes have been further complicated by corrosion and replacement.

d. Mr. Jones exhibited specimens of crinoids and brachiopods from Holland as well as a piece of marble used as a marker to designate the boundary between ancient Egypt and Israel.

e. Dr. F. M. Quodling exhibited specimens of *Leptophloem australie* collected from an *in situ* position close to the rim of the Wolf Creek explosion crater, seventy miles south of Halls Creek Township in the Kimberley Division of Western Australia.

The stem impressions are preserved in orthoquartzites, mapped as Kearney Beds ?Upper Proterozoic, which must now be considered as Devonian in age.

The genesis of the crater, whether meteoric or cryptovolcanic was discussed during a showing of colour slides.

f. Professor T. G. Vallance exhibited specimens from the Undola sill, near Stanwell Park, N.S.W. Evidence of plastic moulding of sediment adjacent to the uppermost contact with igneous material suggests that the Undola body was emplaced among unconsolidated detritus and may be, in fact, a L. Triassic flow. Similar moulded contacts are typical of Permian flows in the Port Kembla-Kiama district.

Annual Report of the New England Branch of the Royal Society of New South Wales

Officers :

Chairman : G. L. McClymont.

Secretary : D. B. Lindsay.

Committee Members : J. H. Priestly, D. D. H. Fayle, R. L. Stanton, R. H. Stokes, N. T. M. Yeates, J. V. Evans.

Branch Representative on Council : D. B. Lindsay.

Four meetings were held as follows :

9th May : Dr. R. J. Goldacre, Chester Beatty Research Institute, London. " The Chemotherapy of Cancer ".

24th June : Professor G. E. Blackman, F.R.S., Sibthorpean Professor of Rural Economy, University of Oxford. " The limits of primary production ".

13th October : Professor F. Fenner, F.A.A., Professor of Microbiology, Australian National University. " Recent advances in animal virology ".

15th February, 1967 : Professor A. Frey-Wyssling, Professor of General Botany, Swiss Federal Institute of Technology, Zurich. " Structure and Ultra-Structure of bell Organelles ".

Financial Statement

Credit : Balance at University of New England Branch, C.B.C. Sydney at May 1966 ..	$205.54
Remittance from Royal Society of New South Wales 1966	50.00
Interest to June 30th, 1966	4.15
Interest to December 30th, 1966 ..	4.59
Debit : Honorarium to Miss C. Betteridge for Secretarial Assistance	6.00
Balance	$258.28

D. B. Lindsay,
Secretary/Treasurer.

Obituaries

1965 - 1966

Robert L. CORBETT (1933)
Thomas J. HOLM (1952)
Charles W. R. POWELL (1921)
George F. SUTHERLAND (1919)
Harold B. TAYLOR (1915)
Sir Robert D. WATT (1911)

1966 - 1967

Sir Neil Huamilto FAIRLEY (1952)
Thelma I. CHRISTIE (1953)
Edward J. KENNY (1924)
Stephen L. LEACH (1936)
Henry J. MELDRUM (1912)
Archibald B. B. RANCLAUD (1919)
Arthur Spencer WATTS (1919)

Sir Neil Hamilton Fairley, who died on 19th April, 1966, was elected an Honorary Member of the Royal Society of New South Wales in 1952.

Neil Hamilton Fairley was born at Inglewood, Victoria, in 1891, the son of James Fairley. He was educated at Scotch College. He studied medicine at Melbourne University, gaining many awards and qualifying M.B., B.S. with first class honours in 1915. He joined the Australian Army Medical Corps and in 1916 he went to Egypt as pathologist to 14 Australian General Hospital where, influenced by Sir Charles Martin, F.R.S., previously Professor of Physiology in Melbourne, he carried out his classical investigations on the pathology, epidemiology and diagnosis of schistosomiasis and published work on malaria, typhus and dysenteries.

At the end of the war Fairley worked under Sir Charles Martin at the Lister Institute in London and in 1920 obtained the D.T.M. & H., and M.R.C.P. He then returned to the Walter and Eliza Hall Institute in Melbourne and shortly after accepted the position of Tata Professor of Clinical Tropical Medicine at the Haffkine Institute, Bombay. Returning to Melbourne in 1926 he again worked at the Hall Institute but in 1928 he left for London, where he was appointed to the staff of the Hospital for Tropical Diseases as Assistant Physician and Director of Pathology, and later as Physician and Director of Clinical Laboratory Research. He also established himself in clinical practice in Harley Street and joined the teaching staff of the London School of Hygiene and Tropical Medicine. At the outset of the Second World War he was a leading figure in Tropical Medicine, and soon after was elected a Fellow of the Royal Society.

Fairley was Consulting Physician to the Australian Imperial Force shortly after Australian units had reached the Middle East. He was a mainstay of the Australian Army Medical Corps and his influence and teaching soon extended throughout the service, and beyond.

At the commencement of war in the Pacific, Fairley was Director of Medicine at Land Headquarters and was later adviser on tropical health, as Chairman of an Inter-Allied Committee, to General MacArthur. The troops were now engaged in highly malarious places of unprecedented difficulty. From the outset, Fairley had already decided to replace quinine with " Atebrin " as a suppressive. Within a few months, the measures now introduced had reduced malarial casualties to negligible proportions. Atebrin suppression of malaria became the order of the day, to the benefit of all.

This was Fairley's greatest contribution to medical science, and his greatest triumph. The importance and value of his findings, freely acclaimed by those in authority at the time, have been in no way diminished by the passage of the years. His work remains an inspiration to those researching in this field.

On his return to London after the war, he was appointed as the first Wellcome Professor of Clinical Tropical Medicine at the London School. He made frequent visits to Australia, on one of the last of which he delivered the McCallum Memorial Lecture.

The James Cook Medal for 1950 was awarded to Sir Neil Hamilton Fairley in recognition of his distinguished contributions to science and human welfare.

He is survived by Lady Fairley and three sons.

Thelma Isabel Christie, a member of the Society since 1953, died on 5th July, 1966.

After graduating B.Sc. from Sydney University, Miss Christie spent one to two years part-time teaching at both Meriden Girls' School and the Presbyterian Ladies College after which she was employed for fourteen years as full-time teacher of Geology and Chemistry at Meriden Girls' School.

From 1952 to 1954 she was employed by the University of New South Wales where she carried out chemical research under the guidance of Professor R. S. Nyholm. From 1955 until her death she was employed by Colonial Sugar Refining Co. Ltd. as Senior Analyst attached to Central Laboratory, Pyrmont.

Miss Christie was also a member of the R.A.C.I., a member of the Chemical Society of the University of New South Wales, an associate member of the Australasian Institute of Mining and Metallurgy and a life member of the Sydney University Women Graduates' Association.

E. J. Kenny was born at Marrickville (N.S.W.) on 6th September, 1895.

He received his early education at Marist Brothers High School Darlinghurst where Leo J. Jones, then an officer of Geological Survey of New South Wales, and afterward Government Geologist, was a tutor in geology. Later he attended Sydney Technical College.

In 1915 he entered the University of Sydney, where he studied geology in the Faculty of Science, as a cadet of the Mines Department. At that time cadets were not permitted to study a full degree course with the result that his studies were restricted to Geology. The result of this was that despite a brilliant academic career he never possessed a degree. He gained High Distinctions in 1st Year and 2nd Year and Honours in Palaeontology at the end of 3rd Year, as well as Professor David's prize for first place in 2nd and 3rd Years.

Mr. Kenny joined the Public Service of New South Wales in December, 1913. His first position was with the Public Works Department where he was engaged on drafting work connected with the proposed Warragamba Dams. In April, 1914 he was appointed to the Geological Survey of New South Wales as Field Assistant. During 1917, he acted as part-time Demonstrator at Sydney University by arrangement between the University and the Mines Department. (Sir Harold Raggatt, former Director of the Bureau of Mineral Resources and former Secretary of Department of National Development was one of his students.)

The first field assignment of E. J. Kenny was as an assistant to L. F. Harper in the survey of the Hill End Gold Field in 1918 and soon after with the same gentleman in his survey of the Yerranderie Silver-Lead Field. For the next three years E. J. Kenny acted as field assistant to E. C. Andrews at Broken Hill. With the help of a subsidy from the mining companies a geological survey of the Broken Hill field was undertaken by Andrews during these years, and the results embodied in Memoir 8 of the Geological Survey " The Geology of the Broken Hill District". E. J. Kenny compiled the chapter summarizing information on the numerous mines outside the Broken Hill Lode and he also surveyed the Pinnacles area (some 10 miles southwest of Broken Hill) in company with E. M. Holder and W. A. Rain. During this time, he also mapped in detail the geology of the then accessible workings of the Broken Hill Mines and did most of the sketch mapping of the geology of the outlying districts such as Thackaringa, Apollyon Valley, Purnamoota, Torrowangue and Euriowie.

This early opportunity of intensive work at Broken Hill was the commencement of a long association with the Barrier Mineral Field involving periodical examination of developments in the various mines as reported in appropriate Annual Reports of the Department.

The appointment of E. J. Kenny as Geological Surveyor in 1925 was for the express purpose of creating a position for the study of underground water, thus opening up a new field of investigation to him. This appointment was the inception of the Department's systematic approach to the problems of the study of ground-water hydrology (previously all investigation had been solely of the Artesian Basins). The initial reconnaissance in the programme embraced four years' coverage of the Dunedoo-Binnaway and Coonabarabran-Gunnedah Districts, the report on the latter having been published recently as Mineral Resources No. 40 (although it was forwarded for printing in 1934).

During the years 1929-31 the reconnaissance of the ground-water of the West Darling District was undertaken and the completed report was published as Mineral Resources No. 36. Mr. Kenny's assistant in this task was another former Under Secretary, Mr. C. St. J. Mulholland. During this survey, for the first time, an official geologist of N.S.W. regularly used a motor car on field work.

Following the West Darling survey, geology and mining activities of the Central North-coast Region (from the confines of Kempsey to Woolgoolga) received his attention for a long period.

E. J. Kenny was promoted to Senior Geological Survey in March, 1937 and was then also appointed a member of the Prospecting Board, and in 1937 and 1938 he undertook a survey of the Captains Flat Field, the old mines having been reopened.

Although most of his work in the preceding decade dealt with hydrology, another field had also claimed some of his energy—the study of oil shale and the problems of extraction of oil from it. During 1930-31 he was Technical Assistant to the Shale Oil Investigation Committee. During 1933-34 he was a member (as a N.S.W. Government Nominee) of the Newnes Investigation Committee and in 1938 he went overseas as N.S.W. Government Delegate to the Glasgow Conference of the British Petroleum Institute. The proceedings of this Conference were related entirely to shale oil. He was deputed to investigate when abroad, problems affecting fuel research and methods of mining thick coal seams.

Kenny's overseas tour in 1938 began with a journey from Mascot to Southampton by air—probably the first example of a N.S.W. State Public Servant travelling air on official business and certainly the first example from this Department. Apart from the research and commercial aspects of production of oil from coal and shale he made visits to the mines and works of Scottish Oils Limited ; to the Leuna Hydrogeneration Plant in Germany producing petrol from brown coal ; to the Fischer Tropsch Gas Synthesis Works at Oberhavsen-Holten in Germany producing petrol and other derivatives ; to shale oil plants in Estonia ; to Unibenzol in Paris ; to the British Fuel Research Station at Greenwich and to the I.C.I. Hydrogeneration Plant at Billingham-on-Tees, England.

In the United States he spent some time at the U.S. Bureau of Mines Field Research Station, and on the Scranton Coalfield investigating hydraulic storage.

His last assignment in the U.S.A. was an unusual one for a geologist. He was to make enquiries and report upon the latest method of taking and recording notes at sessions in Parliament Houses. After receiving relevant information he visited Sacramento, the capital city of California where a mock session of Parliament was arranged to give an opportunity to see the electric system of recording votes in action. His report was forwarded to the then Speaker of the Legislative Assembly in N.S.W.

With the outbreak of World War II and resulting petrol rationing, a number of shale oil works producing " vapourizing spirit " came into being. It was part of his duty to " keep an eye " on the relevant mining and processing activities. A number of reports of the various activities were published and also furnished to the Excise Branch of the Customs Department. At the request of the Hon. the Minister for Mines he was appointed a Director of National Oil Pty. Ltd., in August, 1941, to watch the interests of the State Government as a debenture holder. He was elected Chairman of the Company in August, 1942, upon the resignation of Sir George Davis from the Board. His association with National Oil Pty. Ltd., at Glen Davis occupied some ten years, for most of the time as Chairman of Directors, and for eighteen months in 1946-47 with the additional post of full-time Managing Director resident at Glen Davis.

The appointment of E. J. Kenny, in 1944, to the position of Assistant Under Secretary established the principle of appointment of technical officers to top administrative positions in the Department. He was appointed Under Secretary on 2nd April, 1951. During his Under-Secretaryship in 1956 the Department moved from its quarters in the Lands Department building to Goldsborough House, Loftus Street. He retired on account of ill health on 3rd October, 1957.

E. J. Kenny was active in several spheres outside his official duties with the Mines Department. He

joined the Royal Society of N.S.W. in 1924 and was a Council Member in the period 1940-1942 and was elected Vice-President in the period 1942-1943. In 1940 he was honoured by the invitation to present the Clarke Memorial Lecture to the Royal Society of N.S.W. At the time of his death he was a Life Member of the Society.

In 1926 he joined the Australasian Institute of Mining and Metallurgy as Associate Member. Transfers to Member and Senior Member followed in 1939 and 1960 respectively. He represented New South Wales on the Council of the Institute in 1955-1956.

On a less academic plane his interests were denoted by his membership of the Cricketers Club of N.S.W. and the Pratten Park Bowling Club. In the latter Club he played an active part, holding several administrative positions including that of President, which post he held at the time of his breakdown of health. After his retirement he maintained club membership and continued contact with club activities, but was not able to engage actively in club business or sport.

In yet another area of activity E. J. Kenny was intimately connected with the Australian Museum. He was appointed to the Board of Trustees in 1947 and was Chairman of the Standing Committee at the time of his death.

After his retirement from the Department of Mines his health improved considerably and it was during this period, when engaged in part-time consulting work, that he became something much more than a name to many of the younger geologists of the Department.

The reputation which was known on a personal basis by older geologists and mining men became shared with the younger members of the staff, who will remember his courtesy, approachability, wide knowledge and active mentality, which he retained till his death at the age of 71 on 4th February, 1967.

Stephen Lawrence Leach, who died on 24th March, 1967, had been a member of the Society since 1936.

Mr. Leach received his education at St. Aloysius College, Milson's Point, where he graduated as Dux and then passed on to Sydney University, where he had a distinguished academic record, graduating as N.A., B.Sc.(Hons.) and later on B.Ec.

He was commissioned in the C.M.F. in February, 1934, and throughout World War II he was a major in the Scientific Liaison Bureau.

He had many interests in the scientific, academic and community service fields. He was a fellow of the R.A.C.I. and President of the N.S.W. Branch in 1956 ; he was also a Fellow of the Australian Institute of Management. In the academic field, he was a member of Convocation of all three Universities—Sydney, New South Wales and Macquarie.

Mr. Leach was associated with BALM Paints for 27 years, first as Chief Chemist and later as Director of Research and Development. In 1956 he joined Taubmans Industries Ltd. as Group Personnel Controller, a position which he held at the time of his death.

He is survived by Mrs. Leach, two daughters and a son.

Henry John Meldrum, a member of the Society since 1912, was born on 3rd August, 1882, in the small village of Felled Timber Creek near Tumbarumba, in southern New South Wales. He died at Manly on 28th June, 1966.

During his lifetime he made an outstanding contribution to mathematical education in Australia. His early years were spent in the country around Tumbarumba where he was a pupil under his father at Tumbarumba Public School. Indeed, he finished his formal schooling at this school, but not his education. He did not attend a secondary school, and this fact makes the chronology of his educational development a most interesting one.

On 8th July, 1898, he was appointed a pupil-teacher at Tumbarumba and served in that capacity for 3 years and 9 months. He qualified as a first class pupil-teacher in 1901 and was awarded a full scholarship to the Fort Street Training School from the beginning of 1902. His age was then 19 years and 5 months. At the Training School he continued the study of some academic subjects which no doubt helped him to qualify for matriculation at the University of Sydney in March, 1903 ; it also earned him a 2A Classification as a teacher in the Department of Education.

His first appointment as a teacher was to the Fort Street Model School in 1903, and at the end of that year he was granted permission to enrol in the Faculty of Science in the University of Sydney where he graduated Bachelor of Science at the pass level in 1907. In 1911 he qualified by examination for a 1B Classification in the Department of Education. He read for an Arts degree by evening study and in 1912 he graduated B.A. with first class honours and the University Medal in Mathematics, and was awarded the Barker Scholarship. Following this achievement Mr. Meldrum was invited by Professor Carslaw to assist the evening lectures in Mathematics in the University of Sydney for a number of years.

Following his graduation in Science he was appointed as teacher of science at the Model School, Fort Street, in 1907 and in 1912 was promoted to the position of Master in charge of Science. He remained at Fort Street until he was appointed as Lecturer in Mathematics to the Teachers' College from the beginning of 1913. So in 1913, work in his chosen field, the improvement of the teaching of Mathematics in this State, began.

Mr. Meldrum's work at Teachers' College extended over a period of 34 years.

Mr. Meldrum was a foundation member of the Mathematical Association (N.S.W. Branch) and its Secretary or Joint Secretary from 1920 until his retirement in 1946. He was President in 1955-56. The papers he read to the Association reflect his wide interests—Approximation, Computation, Courses in Secondary School Mathematics in the Australian States, Ability and Performance in Arithmetic, Statistics Applied to Educational Questions, Mathematics in English Schools, Standardised Tests.

Like a number of other persons he had felt for a long time that Mathematics teachers in Australia should have their own journal, and when in 1944 the idea of starting such a journal began to take shape, he entered into the project enthusiastically. The journal came into being as *The Australian Mathematics Teacher* in 1945.

Other ways in which he influenced the teaching of Mathematics stemmed from his work with Syllabus Committees and as an Examiner for the Intermediate Certificate courses in Mathematics.

Mr. Meldrum was highly esteemed by his colleagues not only for his efficiency but also for his courtesy to all.

Archibald Boscawen Boyd Ranclaud, who died at Newcastle on 22nd January, 1967, was well known in academic circles.

The eldest son of the late Colonel and Mrs. Charles Mark Ranclaud, he spent most of his life in Sydney until the past few years when his health began to fail and he returned to Merewether, N.S.W.

Mr. Ranclaud graduated a bachelor of science and bachelor of engineering at the University of Sydney. For many years he was head of the physics department at Sydney Teachers' College and for a period was on loan to the University of Sydney as a physics lecturer.

On his retirement from the Teachers' College he accepted a post in the physics department at the university.

During the war years he gave special lectures in radiology to technicians.

Mr. Ranclaud was well known as an organist. He played at the Great Hall of the University of Sydney on many occasions and at his home church, St. Augustine's Church of England, Merewether. Also, he was an active member of Christ Church St. Laurence, Sydney.

Mr. Ranclaud was a life member of the Royal Society of New South Wales having been elected to membership in 1919. Three papers by him were published in the " Journal and Proceedings ".

He is survived by his two sisters, Mrs. E. Hingston and Miss I. Ranclaud and a brother, Mr. D. Ranclaud.

Arthur Spencer Watts was born at Kidlington, Oxfordshire, England on 27th March, 1881, the youngest son of the late Sidney and Martha Anne Watts ; his father being a landholder in that district.

Mr. Watts was educated in England. A trained horticulturist and seedsman, he came to Sydney in the early years of this century and it was in this field he carried on business until 1951 when he relinquished these interests.

Always interested in the affairs of international and national commerce, he was very active in the Chambers of Commerce—both local and international—and following is a list of the offices he held in those organizations :

President : Australian National Committee of the International Chamber of Commerce—from 1936 to 1940—and Vice-President for several years before, and remained on the Executive Committee of this body until the time of his death.

President : Sydney Chamber of Commerce—1932/33 and 1933/34.

President : Associated Chambers of Commerce of the Commonwealth of Australia—1933/34.

Chairman : Taxation Committee, Sydney Chamber of Commerce, from its inception in 1925 until he resigned in 1937.

Vice-President : New South Wales Branch Institute of International Affairs, and Member of the Commonwealth Council.

Representative, Sydney Chamber of Commerce, in 1926 in the matter of the reorganization of the financial relations of the Commonwealth and State and the coordination of Loan Policy at the Perth Conference.

Gave evidence for the Sydney Chamber of Commerce before the Royal Commission on Taxation in 1932.

Stated the case for the Sydney Chamber of Commerce before the Select Committee of the Senate on the Central Reserve Bank Bill.

Gave evidence for the Sydney Chamber of Commerce and the Employers' Federation before the Royal Commission on Banking in 1936.

When Chairman of Parliamentary Sub-Committee of the Council of the Sydney Chamber, gave evidence before Royal Commission enquiring re matters concerning the promotion and operations of certain Companies in N.S.W.

Was Leader of the Australian Delegation to the International Chamber of Commerce Conference in Washington in 1931, one outcome of which was the Hoover Moratorium of that year, and in 1935 led the Australian Delegation to the Paris Conference of the I.C.C.—one important result of which was the Tripartite Monetary Agreement of September 1936 (Great Britain, U.S.A. and France). As a result of the active part taken in discussion on the international conflict between the three great sections, viz. sterling area, gold bloc, and the dollar group, was invited by the German representatives to go to Berlin and discuss monetary and currency matters with Dr. Schacht, then head of the Reichsbank—which invitation was accepted. In 1939 led the Australian Delegation to the Copenhagen Conference of the International Chamber. Leader of the delegation arranged by the Australian National Committee of the International Chamber of Commerce to represent Australia at an International Business Conference held at Westchester Country Club, Rye, New York, U.S.A. in 1944. Also Leader of the Australian Delegation to the International Chamber Congress held in Lisbon in 1951.

In 1939 attended the International Wool Conference in Brussels as the representative of the British National Committee of the International Chamber of Commerce.

In 1935 visited China and Japan calling at Tokyo, Shanghai, Hong Kong, Peking etc. and attended conferences of various organizations on trade relations. Report of his conclusions published in 1936 re the Far Eastern situation with particular reference to Japan is significant in view of subsequent developments.

In 1941 he made a tour of N.S.W. country districts on behalf of the War Loan drive.

Mr. Watts was a member of the Society for many years, having been elected to membership in 1921.

Medallists, 1966-67
Citations

Clarke Medal for 1967

Professor Spencer Smith-White, D.Sc.Agr., F.A.A.

Professor Smith-White, Professor of Biology (Genetics), University of Sydney since 1963, was born in Sydney on 14th April, 1909. He is a graduate of the University of Sydney and, after holding various early appointments, including a research position in plant breeding with the N.S.W. Department of Agriculture, he joined the scientific staff of the Museum of Applied Arts and Sciences in 1937 as officer in charge of the Botanical Section. Here he laid the foundations for his lifelong interest in cytology, particularly of the Australian Flora. This interest was transferred to the Botany Department of the University of Sydney to which he was appointed lecturer in 1947, subsequently receiving promotion to senior lecturer and then to reader. In 1961 he was Acting Professor of Botany and during the following year he was elected a Fellow of the Australian Academy of Science.

The W. B. Clarke Medal for 1967 is conferred on Professor Smith-White in recognition of his distinguished contributions to Botany, more especially in the field of cytology, genetics and evolution of the Australian Flora.

The Society's Medal for 1966

Mr. H. A. J. Donegan, M.Sc., F.R.A.C.I., F.R.I.C.

Mr. Donegan was born in England in 1902 and came to Australia in 1912.

After forty-seven years of service with the Department of Mines N.S.W., he retired as Chief Analyst. Mr. Donegan was the first in Australasia to investigate coal and oil shales by low temperature carbonization, to determine the explosibility of coal and shale mine dusts and other dusts ; to test self-contained breathing apparatus used in mine work ; to investigate and recommend use and conditions of use of diesel locomotives in underground mines ; to determine ash fusion points of Australian and New Zealand coals and to thoroughly appraise the oil shale seam at Glen Davis. He is the author of a number of Departmental publications and reports and many articles in technical journals both in Australia and Great Britain.

Mr. Donegan was elected to membership of the Society in 1929 and was made a life member in 1964. He served on the Council for 13 years, being Honorary Treasurer in 1952 to 1957, was Vice-President 1958 to 1959 and President in 1960.

This award is made to Mr. Donegan in recognition of his scientific contributions and for his services to the Society.

James Cook Medal for 1966

Sir William Hudson, K.B.E., F.R.S.

Sir William Hudson was born in New Zealand and was educated at Nelson College. He studied at the University of London, from which he graduated B.Sc. in Engineering with First Class Honours. He took a post-graduate course in Hydro-Electric Engineering at Grenoble, France.

Sir William has had a long career in hydro-electric work and dam construction. Early in his career he was an Assistant Engineer with the hydro-electric section of Armstrong, Whitworth & Co., London. Returning to New Zealand he was the Engineer-in-Charge of construction of the Arapuni Dam. After further experience in New Zealand he came to Australia and joined the Sydney Water Board as Assistant Resident Engineer on the construction of the Woronora Dam, later becoming Chief Construction Engineer and then Engineer-in-Chief of the Sydney Water Board. During this time he was associated with such major projects as the Captain Cook Graving Dock and Warragamba Dam.

The Commonwealth Government, in 1949, invited him to accept the appointment as Commissioner to launch and implement the Snowy Mountains Hydro-Electric Scheme. Under his direction the Snowy Mountains Hydro-Electric Authority has carried out a vast and complex programme of river diversion works, dam construction and hydro-electric projects, great by world standards.

The Edgeworth David Medal for 1966

Roger Ian Tanner, Ph.D.

Dr. Tanner was born on 28th July, 1933. He gained the B.Sc. degree with First Class Honours in Mechanical Engineering in the University of Bristol in 1956. He proceeded to the United States for further study on a King George VI Memorial Fellowship graduating M.S. in Electrical Engineering in the University of California at Berkeley in June, 1958.

After serving as Lecturer in Mechanical Engineering in the University of Manchester from 1958-61 he took up a position as Senior Lecturer in Mechanical Engineering in the University of Sydney early in 1962 being promoted to a Readership in 1964. He moved to an Associate Professorship in Engineering at Brown University, Providence, Rhode Island, in August, 1966.

Dr. Tanner's research interests are very wide and he has made contributions in a number of areas. His list of publications is very extensive; twenty-three were written during the five-year period he was in Sydney.

Archibald D. Ollé Prize

Raymond Albert Binns, B.Sc.(Syd.), Ph.D.(Cantab.)

Dr. R. A. Binns was awarded the degree of Bachelor of Science with First Class Honours in Geology in 1959 and shared the award of the University Medal and the Deas Thompson Scholarship.

He spent the period 1959-1962 working in the Department of Mineralogy and Petrology at Cambridge University, gaining the degree of Doctor of Philosophy for his thesis entitled " Metamorphism at Broken Hill".

Dr. Binns accepted an appointment as lecturer in Geology at The University of New England, Armidale, in September 1962 and was promoted to the position of senior lecturer in January 1966.

Following more detailed research work at Broken Hill, Dr. Binns turned his attention to New England where he studied the distribution and metamorphism of the little known Permian rocks. It was for a paper on this work, accepted for the Browne Volume of the Society's publications, that he has been awarded the Ollé Prize, the title of the paper being " Granitic Intrusions and Regional Metamorphic Rocks of Permian Age from the Wongwibinda District, North-eastern New South Wales ".

Rules

1. *The aims of the Society*

The aims of the Society shall be to encourage studies in Science, Art, Literature and Philosophy, to promote and further the development of Science and allied disciplines and their applications, to facilitate the exchange of information and ideas amongst the members of the Society and others on Science and kindred topics and to disseminate knowledge relating to Science and allied disciplines and for that purpose the Society may

(i) hold meetings for reading and discussing communications ;
hold and promote congresses, conferences and exhibitions ;
print, publish, sell, lend or distribute the proceedings or reports of the Society or any papers, communications, works or treatises ;
make grants of money, books, apparatus or otherwise for the purpose of promoting research or otherwise advancing knowledge ;
promote and encourage education and training in Science, Art, Literature and Philosophy and subjects related thereto ;
invite the co-operation of kindred societies and technical bodies, in any manner calculated to promote the objects of the Society ;
establish and maintain libraries and collections ;
institute and establish and accept trust funds for the purposes of scholarships, grants, awards, prizes and other distinctions ;
publicise any significant achievements and endeavours in Science, Art, Literature and Philosophy ;
provide reading, writing and social rooms and facilities for members of the Society, their friends and guests ;
speak and act publicly or privately on matters of interest to the Society.

(ii) purchase hire lease or otherwise acquire and hold for the purposes of the Society real and personal property and any rights and privileges and (so far as the law may from time to time allow) sell demise let mortgage or dispose of all or any such real and personal property rights and privileges.

(iii) enter into any arrangements or contract with any government or other companies, corporations, public body or other authorities with a capital Supreme, municipal, local or otherwise that may seem conducive to the Society's objects or any of them and to obtain from any such government, company, corporation, public body or other authority any rights, privileges and concessions which the Society may think it desirable to obtain and to carry out exercise and comply with any such rights, privileges and concessions.

(iv) hire and employ such persons as may be considered necessary for the purposes of the Society and to pay to them and to other persons in return for services rendered to the Society salaries, wages, gratuities and pensions and make payments towards insurance and form and contribute to provident and benefit funds for the benefit of any person employed by the Society.

(v) invest and deal with any monies of the Society not immediately required for the purpose thereof upon such securities and in such manner as may be determined and from time to time vary and realise such investments.

(vi) enter into any insurance agreement in respect to any matter in keeping with the objects of the Society.

(vii) draw accept endorse discount execute and issue cheques promissory notes bills of exchange warrants debentures and other negotiable or transferable instruments or securities.

(viii) borrow money from time to time and for such purpose give debentures liens mortgages charges or other securities over whole or any part of the property real or personal of the Society (so far as the law may allow) enter into agreements bonds or covenants with the lender stipulating for a collateral advantage.

(ix) establish subscribe or make advances or donations to promote become a member of affiliate with support or co-operate with any other association or person (whether incorporated or not) whose objects are altogether or in part similar to those of the Society or will promote those of the Society.

(x) do all or any of the above things in any part of the world.

(xi) do or concur in the doing of such acts deeds matters and things and enter into and make such arrangements as are incidental and conducive to the attaining of the above objects or any of them and establish funds for the carrying out of the above objects.

In fulfilling the above objects particular attention shall be given to such topics as tend to develop the resources of Australia and to illustrate its natural history and production.

2. *Patrons*

The Governor-General of the Commonwealth and the Governor of New South Wales shall each be invited to accept the office of Patron.

3. *Members of the Society*

Members of the Society shall be persons desirous of furthering the aims of the Society and who have been elected in accordance with the Rules and By-laws of the Society.

4. *Rights, Privileges and Obligations of Members*

(*a*) Members shall have the right and privilege

(i) to attend meetings of the Society, its Branches and Sections ;

(ii) to receive a copy of each publication authorised by Council for gratis distribution to members ;

(iii) to use the library in accordance with the By-laws ;

(iv) to submit papers and to take part in discussions.

(*b*) No person shall be considered for election unless he has signed the following Obligation :

I, the undersigned, do hereby engage that I will endeavour to promote the interest and welfare of the ROYAL SOCIETY OF NEW SOUTH WALES, and to observe its Rules and By-laws as long as I shall remain a member thereof.

5. *Termination of Membership*

(*a*) Any member of the Society not indebted to the Society for subscription or otherwise may resign membership by giving notice to the Honorary Secretaries.

(*b*) Any member unfinancial for two years may be expelled by resolution of the Council. Such member may be re-admitted on giving a satisfactory explanation to the Council and meeting his financial obligation to the Society.

(*c*) The Council shall have the power to expel any member from the Society provided that such resolution is agreed to by at least twelve (12) of the members present. Before a resolution for expulsion is passed the member concerned shall be afforded any opportunity of presenting any explanation or defence he may think fit.

6. *Honorary Members*

A person of eminent learned attainment or a person who has been a benefactor of this or some other Australian state or a distinguished promoter of the Society may be admitted as an Honorary Member of the Society. The number of Honorary Members shall not at any time exceed twenty. Honorary Membership shall be bestowed in accordance with the By-laws of the Society and on not more than two persons in any one year.

Honorary Members shall be exempted from payment of fees and contributions ; they may attend the meetings of the Society and they shall be furnished with copies of the publications of the Society but they shall have no right to hold office, to vote or otherwise take part in the business of the Society.

7. *Associates*

Persons may be admitted as Associates of the Society or have their Associateship terminated in accordance with the By-laws.

The rights and privileges of an Associate are as set out in the By-laws.

8. *The Council of the Society*

The Business, Properties and Affairs of the Society shall be managed by the Council of the Society which shall consist of

(i) The President ;

(ii) Five Vice-Presidents of whom one shall be the immediate Past-President if available ;

(iii) an Honorary Treasurer ;

(iv) an Honorary Librarian ;

(v) two Honorary Secretaries ;
(vi) one representative from each of the Branches ;
(vii) eight ordinary Members of Council.

9. *The Executive Committee*

(*a*) There shall be an Executive Committee which shall deal with any matters referred to it by Council and with any matters which concern the Council with regard to which action should not, in the opinion of the Executive Committee, be postponed until a meeting of the Council. In respect to all such matters the Executive Committee shall have and may exercise between meetings of the Council all powers and functions of the Council except

(i) to make, alter or repeal By-laws ;
(ii) approve of the expulsion of a member or an associate under Rules 5(*b*) and 6 ;
(iii) create or dissolve a Branch or a Section of the Society or vary the geographical territory of a Branch ;
(iv) declare the office of a member of Council vacant ;
(v) fill a vacancy on the Council.

(*b*) The Executive Committee shall report on any action taken under (*a*) above to the Council meeting immediately following such action.

(*c*) The Executive Committee shall consist of the President, the Honorary Secretaries, the Honorary Treasurer, the Honorary Librarian and the immediate Past-President.

(*d*) The quorum for an Executive Committee meeting shall be three.

10. *Election of Members of Council*

(*a*) The President, Vice-Presidents, Honorary Treasurer, Honorary Librarian, the Honorary Secretaries and the eight ordinary Members of Council shall be elected at the Annual General Meeting ;

(*b*) The representative of any Branch shall be chosen by that Branch ;

(*c*) The declaration of the result of the election of Members of the Council shall be the last item of formal Business at the Annual General Meeting. The newly elected Council shall take office immediately the declaration is made ;

(*d*) Any financial member of the Society shall be eligible for nomination for any position on the Council of the Society except that no member shall be eligible for election as

(i) President if he has served as President for the whole of the preceding year ;
(ii) an ordinary Member of the Council if he has been elected to the Council for the five preceding years ;

(*e*) Provision shall be made for any financial members of the Society to record an absentee vote as set out in the By-laws ;

(*f*) No ballot for the election of members of the Council shall be valid unless twenty members at least record their votes ;

(*g*) Election shall be conducted in accordance with the By-laws ;

(*h*) Any vacancy on the Council may be filled by election at a Council Meeting. Members of the Society shall be notified at the first general meeting following such action.

11. Subject to these rules, questions arising at any meeting of the Council or of the Executive Committee shall be decided by a majority of the votes cast by members and their proxies. Each member present shall have one vote. The Chairman shall have a deliberative vote and a casting vote.

12. *Termination of Membership of the Council*

The office of a Member of the Council shall be vacated if

(i) he ceases to be a member of the Society ;
(ii) he, by notice to the Society, resigns his office ;
(iii) he absents himself from three consecutive meetings without reasonable excuse ;
(iv) his office is declared vacant by a resolution of the Council on the grounds that he is no longer able to carry out the duties of his office through prolonged illness or other causes ;
(v) he, not being a representative of a Branch, his office is declared vacant by a resolution of a general meeting of the Society at which at least 25 financial members are present ; or being a representative of a Branch his office is declared vacant by a resolution of a meeting of the members attached to that Branch ;
(vi) he becomes bankrupt or makes any arrangement or composition with his creditors ;

(vii) he is found lunatic or becomes of unsound mind ;

(viii) he is directly or indirectly interested in any contract or proposed contract with the Society and fails to declare the nature of interest to the remaining members of the Council.

13. *Council Meetings*

(*a*) The Council shall meet during the fortnight preceding each general meeting of the Society.

(*b*) The Honorary Secretaries shall call a meeting of the Council
  (i) by resolution of Council ;
  (ii) at the request of the President ;
  (iii) at the request of three members.

(*c*) Due notice, in writing, shall be sent to each Member of the Council at least three days before such meeting.

(*d*) The quorum for meetings of Council shall be six members.

(*e*) The representative of a Branch may, by instrument in writing, appoint a member of the Society as his proxy to act on his behalf at any or all meetings of the Council which he is unable to attend.

(*f*) At meetings of the Council and of the Executive Committee, the President or in his absence the Past-President or in his absence one of the Vice-Presidents shall be chairman. In the absence of the President and Vice-Presidents the members and proxies present shall choose one of their number to be chairman.

14. *Duties of the Executive Members of Council*

The duties of the Executive Members of Council are as set out in the By-laws.

15. *Committees*

(*a*) The Council may appoint Committees consisting of such member or members of the Council and such other persons as it thinks fit.

(*b*) The President, the Honorary Treasurer and the Honorary Secretaries shall be members *ex officio* of all such Committees.

(*c*) Any Committees so formed shall
  (i) work within the terms of reference prescribed for it by the Council and
  (ii) report its findings and/or actions to Council.

16. *Branches*

(*a*) To further its objects the Society may establish Branches on a geographical basis.

(*b*) The Council may establish or disestablish a Branch or vary the geographical territory of a Branch.

(*c*) Each Branch shall be constituted and its affairs shall be carried out in accordance with these Rules and with the provisions of the By-laws from time to time in force.

(*d*) Except as otherwise provided in the By-laws the members of the Society normally resident in the territory of a Branch shall be members of that Branch.

17. *Sections*

(*a*) To further its aims within specific subjects, the Society may establish Sections.

(*b*) The Council may establish or disestablish a Section.

(*c*) A Section shall be constituted and its affairs shall be carried out in accordance with these Rules and with the provisions of the By-laws from time to time in force.

18. *Meetings of the Society*

The meetings of the Society shall comprise the Annual Meeting, Ordinary General Meetings and Special Meetings.

At least seven days' notice of each meeting shall be given to members.

(*a*) The Annual General Meeting of the Society shall take place during the month of April. Unless the Chairman decide otherwise the Business shall be transacted in the following order:
  Minutes of the preceding Annual General Meeting
  Ballot for Election of Members
  Introduction and Admission of New Members
  Announcement and Presentation of Awards
  Presentation of the Annual Report of the Council
  Presentation and Annual Report of the Honorary Librarian
  Presentation of the Annual Income and Expenditure Account and the Balance Sheet of the Society
  Election of Auditor
  Ballot for Election of Members of the Council (if required)

The Address of the Retiring President
Announcement of the Result of the Election of Members of Council
Installation of the President-Elect

(*b*) There shall be at least eight Ordinary General Meetings each year. These meetings shall be held on the first Wednesday of the month unless otherwise decided by the Council.
Unless the Chairman decide otherwise, the Business of the Ordinary General Meeting shall be in the order prescribed in the By-laws.

(*c*) The Council may whenever it thinks fit and shall on the receipt of a written request signed by at least 30 members convene a Special Meeting.

19. Subject to these Rules questions arising at any meeting of the Society shall be decided by a majority of the votes cast by the members present. Each member present shall have one vote. The Chairman shall have a deliberative vote and a casting vote.

20. A notice may be given by the Society to any member either personally or by sending it by post to him at his address supplied by him to the Society for the giving of notices to him.

21. *Visitors*

Visitors may be admitted to the meetings of the Society in accordance with the provisions of the By-laws.

22. *Publications*

The conditions relating to the submission, acceptance or otherwise and publications of material by the Society shall be as prescribed in the By-laws.

23. *Subscriptions*

(*a*) Conditions relating to the payment and remission of application fees, annual subscriptions and levies of members and associates shall be as prescribed in the By-laws.

(*b*) Members and Associates may not be levied in any one year in excess of one annual subscription over and above the annual subscription fixed for that year.

(*c*) Council shall have the power to waive or alter the application fees, annual subscriptions and levies in special circumstances.

24. *Alteration to the Rules of the Society*

No alteration or addition to the Rules of the Society shall be made unless

(i) the full text of the resolution proposing the alteration or addition shall be communicated in writing to the Honorary Secretaries who shall place it on the next notice paper for an ordinary general meeting ;

(ii) the resolution is placed on the notice paper for and submitted to a subsequent ordinary general meeting or special meeting held not less than 6 days after the meeting referred to in (i) above, at which at least 30 members are present and two-thirds of the members present support the motion ;

(iii) the resolution is placed on the notice paper for and submitted to a further meeting held not less than 6 days after the meeting referred to in (ii) above at which at least 25 members are present and the majority of those voting support the motion.

25. *By-laws*

The Council shall make, alter or repeal such By-laws as it deems necessary to regulate the affairs of the Society provided that such changes in the By-laws shall be notified to all members of the Society not less than 7 days before an ordinary general meeting. Such amendment shall become operative after that meeting unless a resolution to the contrary is passed at that meeting.

26. *The Seal*

The Council shall provide for the safe custody of the Seal which shall be used only by authority of the Council and every instrument to which the Seal is affixed shall be signed by two members of the Council.

27. *Management of Funds and Property*

(*a*) The Council shall have control over the management of the funds and of the property of the Society.

(*b*) Accounts and Audit

(*ba*) The Council shall cause books of account to be kept in such a manner as properly represent the state of the Society's affairs and explain its transactions and to enable them to be conveniently and properly audited.

(*bb*) The books of account shall be kept at the office of the Society or at such other place as the Council shall think fit and shall always be open to inspection of members of the Council. They shall be open for inspection by members during business hours and shall be subject to any reasonable restrictions which may from time to time be laid down by the Council.

(*bc*) The financial year of the Society shall terminate on the last day of February.

(*bd*) The Council shall cause to be prepared and placed before the Society at its Annual General Meeting an Annual Income and Expenditure account and Balance Sheet made up to the end of the financial year immediately preceding the Annual General Meeting.

(*be*) The Annual Balance Sheet shall be signed on behalf of the Council by two members thereof and shall have attached to it a report by the Council with respect to the state of the Society's affairs and the auditor's report, all of which shall be printed in the Proceedings of the Society.

(*bf*) One or more auditors who shall be Chartered Accountants or Public Accountants shall be elected each year at the Annual General Meeting to audit the affairs of the Society for the ensuing year.

An auditor may be removed from office by a resolution passed by not less than two-thirds of those voting at a Special Meeting called for the purpose. The quorum for such a meeting shall be 30 members.

Council shall have the power to fill any casual vacancy in the office of auditor of the Society.

By-Laws

1. *Members of the Society*

(*a*) Every candidate for admission as a member of the Society shall be recommended according to a prescribed form of certificate (Appendix A) by not less than two members to one of whom the candidate must be known personally.
The certificate together with the entrance fee and the first annual subscription shall be delivered to one of the Honorary Secretaries and shall be considered at the next ensuing Council Meeting. The names shall be placed on the notice paper of the following two ordinary general meetings of the Society and shall be read at those meetings.

(*b*) The vote for election of a new member shall take place at the meeting at which the certificate is read for the second time, provided not less than twenty members are present ; otherwise it shall be deferred until the first meeting thereafter at which not less than twenty members are present. The election shall only be agreed to if at least four-fifths of the members voting express their approval.

(*c*) Any candidate whose election has not been agreed to shall have the annual subscription refunded.

(*d*) Every new member shall be notified of his election and shall be supplied with a list of members and a copy of the Rules of the Society.

(*e*) At the first ordinary general meeting at which a new member attends after election he shall be presented to the Chairman who addressing him by name shall say " In the name of the Royal Society of New South Wales I welcome you as a member thereof."

2. *Associates*

(*a*) On the recommendation of one member of the Society on a prescribed form of certificate the Council may admit as an associate
 (i) a person under the age of 25 years or
 (ii) a close relative of a member.

(*b*) An associate shall have the right
 (i) to receive notice of and attend meetings of the Society, its Branches and Sections
 (ii) to read in the library
 (iii) to submit papers and to take part in discussions at meetings of the Society, its Branches and Sections.

(*c*) An associate shall not have the unqualified right
 (i) to receive, free of charge, any publication of the Society
 (ii) to borrow books or periodicals from the library
 (iii) to vote at any meeting of the Society, its Branches and Sections
 (iv) to hold office on the Council.

(*d*) Associateship shall be terminated
 (i) by the associate submitting a notice in writing to the Honorary Secretaries
 (ii) by the associate ceasing to qualify under (*a*) above
 (iii) by motion of the Council if not less than two-thirds of those voting express approval of such termination.

(*e*) Every new associate shall be notified of his admittance.

(*f*) The name of each new associate shall be placed on the notice paper of the ordinary general meeting immediately following his admission.

3. *Honorary Members*

Honorary Members shall be elected on the unanimous vote of Council. The election shall be communicated to members at the next following general meeting of the Society.

4. *Fees, Subscriptions and Levies*

(*a*) Honorary Members of the Society shall not be required to pay any application fee, annual subscription or levy.

(*b*) All matters of doubt relating to fees, subscriptions or levies shall be decided by the Council.

(*c*) An application fee as set out hereunder shall accompany each application for membership or each application to become an associate of the Society. This fee shall remain the property of the Society. Fee for application to become a member when
   (i) applicant is not an associate $3.00
   (ii) applicant is an associate $2.00
Fee for application to become an associate $1.00

(*d*) (*da*) The annual subscription to be referred to the Finance Committee for decision by April.

(*db*) Annual subscriptions lodged with applications shall be returned to the applicant if for any reason the applicant does not become a member or associate of the Society as the case may be.

(*dc*) The annual subscription shall become due on the first day of April for the current financial year.

(*dd*) Life membership to be compounded by members over sixty (60) only.

x \ N	10	15	20	25	30	35
60	78	72	64	50	30	0
65	72	66	58	48	30	0
70	66	60	52	44	28	0
75	60	54	48	40	28	0

N = number of subscriptions already paid by a member.
x = age of member.

(*de*) The annual subscriptions for an associate who has paid a Life Composition fee and who transfers to membership shall be the difference between the annual subscription for a member and for an associate. The life composition fee in such a case shall be the difference between the appropriate fees corresponding to the age of the applicant at the time he compounds his membership subscription.

5. *Election of Council*

(*a*) Any financial member who is not disqualified by the Rules of the Society may be nominated for any position on the Council. Such nomination, signed by two members of the Society and countersigned by the nominee, shall be notified to the Honorary Secretaries before the first day of January.

(*b*) After receipt of nominations from members of the Society, the Council may make additional nominations, if deemed necessary, and shall ensure that there are, at least, sufficient candidates to fill all positions on the incoming Council.

(*c*) A complete list of the names, in alphabetical order, of those correctly nominated for each position, together with the nominators, shall be posted to each financial member of the Society not less than 21 days before the day appointed for the Annual Meeting.

(*d*) The retiring Council shall appoint a Returning Officer for the election.

(*e*) Should no ballot be necessary, the Returning Officer shall advise the Council and those nominated shall be declared elected at the next Annual General Meeting.

(*f*) Where an election is required, such election shall be by secret ballot. Each member voting shall be entitled to vote for as many candidates as there are vacancies to be filled. Those candidates receiving the greater number of votes shall be declared elected.

(*g*) The ballot for the election of the Council shall take place at the Annual General Meeting. However, any member may make a postal vote if desired.

(*h*) The ballot paper for the election of the Council shall contain in alphabetical order names of candidates correctly nominated for each position on the Council.

6. *Postal Vote for the Ballot for Election of the Council*

(*a*) A member desiring to cast a postal vote shall notify the Returning Officer in writing in sufficient time before the date of the ballot, and in any case at least fourteen days before such date.

(*b*) On receipt of such notification, the Returning Officer shall forward a ballot paper to the member.

(*c*) The ballot paper duly marked shall be invalid unless returned to the Returning Officer before 12 noon on the day which the ballot takes place.

7. *Duties of the Honorary Secretaries*

(*a*) The Honorary Secretaries shall
   (i) conduct all the correspondence of the Council and the Society

(ii) attend all meetings of the Council and all meetings of the Society and take and record the minutes of such meetings
(iii) edit the Journal and Proceedings of the Society
(iv) be responsible for the safe custody of books, maps, specimens and other property of the Society
(v) acknowledge all donations to the Society
(vi) give due notice of all meetings of the Society and the Council
(vii) keep a record of attendances at the Council meetings.

(*b*) With the approval of the Council, the Honorary Secretaries may delegate any of the above duties to a member of the Council or to an employee of the Society.

8. *Duties of the Honorary Treasurer*

(*a*) The Honorary Treasurer shall
(i) receive all monies paid to the Society and deposit such monies into the account or the accounts of the Society
(ii) make such disbursements as shall be authorized by Warrant from the Council
(iii) keep all financial books and financial records of the Society
(iv) arrange for the audit of the Society's accounts at such times as shall be directed by the Council
(v) prepare and present a duly audited Annual Balance Sheet for the financial year of the Society.

(*b*) With the approval of the Council, the Honorary Treasurer may be assisted in any of the above duties by a member of the Council or by an employee of the Society.

9. *Library*

(*a*) To assist the Council in the control of the Library, the Council may appoint a Library Committee, the powers, duties and terms of reference of which shall be determined by the Council.

(*b*) The Library shall be open for the use of members daily, Monday to Friday, from 9.30 a.m. to 4.30 p.m. except in the absence of the staff.

(*c*) Any publications or other item in the Library shall be available for reference by members in the Library, and shall not be removed without the Librarian's permission.

(*d*) Members may borrow a publication from the Library for a period not exceeding fourteen days subject to signing for it in the Librarian's record. Borrowing shall normally be for a period not exceeding fourteen days but an extension of time may be arranged on application.

(*e*) Any publication not returned when requested by the Honorary Librarian, or returned damaged, shall be replaceable at the expense of the borrower.

(*f*) Members requiring a copy of an article must first obtain the consent of the Honorary Librarian and must bear the expense of reproduction.

10. *Order of Business at an Ordinary General Meeting*

Minutes of the previous Ordinary General Meeting
Minutes of all Special Meetings held after the previous Ordinary General Meeting
Business arising out of the Minutes
Announcement of names of candidates for membership
Ballot for election of members
Introduction and Admission of new members
Communications from the Council
Communications from the Branches and Sections
Motions from the preceding Ordinary General Meeting
Announcement of papers accepted for publication in the Journal
General Business
Special Business

The Chairman shall be the sole arbiter on the nature of the General Business transacted at meetings.

The Chairman shall have a deliberative and a casting vote on any motion.

11. *Visitors*

It shall be competent for the Council or the Chairman to restrict attendance of visitors at meetings.

12. *Publications*

(*a*) Material submitted by members for publication or by communication to the Society shall be addressed to the office of the Society, Science House, 157 Gloucester Street, Sydney.

(*b*) Material submitted for publication shall be in duplicate and accompanied by four copies of an abstract and shall be submitted in accordance with the Society's " Instructions to Authors ".

(*c*) The receipt of material shall be acknowledged by the Honorary Secretaries.

(*d*) No material shall be published or formally communicated to members except with the approval of the Council. Material not accepted by the Council shall be returned to the author forthwith.

(*e*) The original copy of any material accepted for publication by the Society together with illustrations, diagrams, etc., shall become the property of the Society and will not necessarily be returned to the author.

(*f*) (*fa*) The author of material which is accepted for publication by the Society shall not publish such material elsewhere, except with the permission of the Council until the paper or an abstract thereof shall have appeared in a publication of the Society.

(*fb*) Reproduction of a paper, or part thereof, by any mechanical or photographic means whatsoever is prohibited except with the written consent of the Council.

(*g*) Except in special circumstances, material from non-members will not be accepted for publication.

(*h*) The author shall be liable for costs occasioned by alterations or additions made to material, at his request, at or after the submission of the printer's proofs.

(*i*) Reprints shall be supplied to authors under the following conditions :

(*ia*) Twenty-five (25) free copies shall be provided of each paper published.

(*ib*) Additional copies of reprints may be obtained at rates obtainable from the Society's office provided that such reprints are ordered when the printer's proofs are returned to the Honorary Secretaries.

13. *Branches*

(*a*) There shall be a New England Branch of the Society whose region shall extend fifty miles from Armidale.

(*b*) (*ba*) A member of the Society who is normally resident in a region in which there is a Branch shall be deemed a member of that Branch.

(*bb*) Membership of the Branch shall cease

(i) on the resolution of the Council at the request of the Branch Committee or

(ii) if the member submits his resignation from the Branch in writing to the Honorary Secretaries of the Society or the Honorary Secretary of the Branch or ceases to be a member of the Society or ceases to reside within the region of the Branch.

(*bc*) A member not normally resident within the region of a Branch may at his own request and with the agreement of the Branch Committee be made a member of a Branch by the Council.

(*bd*) Membership of a Branch shall not entail any additional application fee or membership subscription from a member of the Society.

(*c*) An associate of the Society may be attached to a Branch and the provisions of the preceding By-law for membership of the Branch shall apply, *mutatis mutandis*, to such attachment.

(*d*) A Branch may frame Rules for the conduct of its own affairs within the framework of the Rules and By-laws of the Society; such Rules shall be subject to the approval of the Council.

(*e*) (*ea*) The management of a Branch shall be vested in a Branch Committee which shall consist of a Chairman, Vice-Chairman, Honorary Secretary, Honorary Treasurer and such other members as may be decided by the Branch. One member of this Committee shall be the representative of the Branch on the Council. The offices of Honorary Secretary and Honorary Treasurer may be combined.

(*eb*) Only members of the Branch shall be eligible for election to the Branch Committee.

(*f*) (*fa*) The first Committee of a Branch shall be elected at a meeting convened by the Council to inaugurate the Branch. At such a meeting only members of the Society normally resident within the region of the Branch shall be eligible for election or eligible to vote.

(*fb*) The Committee of a Branch shall be elected annually at the Annual General Meeting of the Branch.

(*fc*) No member of the Branch Committee shall retain office if he ceases to be a member of the Branch.

(*fd*) In the event of the position of Chairman of a Branch becoming vacant this position shall be filled by the Vice-Chairman or if he is unavailable the Branch Committee shall elect a Branch Chairman from among the members of the Branch.

(*fe*) A casual vacancy on a Branch Committee, other than in the position of Branch Chairman, shall be filled by the Branch Committee at its discretion.

(*g*) (*ga*) An Annual General Meeting of the Branch shall be held each year in the month of March at which a written report of the activities and finances of the Branch shall be presented and at which officers shall be elected for the ensuing year. A copy of the written report shall be forwarded to the Council before 15th March each year.

(*gb*) Ordinary meetings of a Branch shall be convened by the Committee at such times and places and in such manner as the Committee decides.

(*gc*) The Committee may when it thinks fit convene a Special Meeting of the Branch. It shall convene such a meeting on receipt of a request signed by at least ten per cent of the membership of the Branch or by five members, whichever is the greater.

(*gd*) No business shall be transacted at the Annual General Meeting or Special Meeting of a Branch unless ten per cent of the membership of the Branch or five members, whichever is the greater, are present.

(*h*) (*ha*) The Council may contribute from the funds of the Society towards the formation and maintenance of a Branch.

(*hb*) The Committee of a Branch shall have power to accept monies and spend these in addition to those granted to it by the Council provided such monies are used solely to further the objects of the Society.

14. *Sections*

(*a*) There shall be a Geological Section of the Society.

(*b*) Any member of the Society shall be entitled to become a member of a Section without any additional fee.

(*c*) The management of a Section shall be vested in a Committee which shall consist of a Chairman, Honorary Secretary and such other members as may be decided by the Section.

(*ca*) The first Committee of a Section shall be elected at a meeting convened by the Council to inaugurate the Section.

(*cb*) The Committee of a Section shall be elected annually at a general meeting of the Section to be held in March.

(*d*) A report of the year's proceedings shall be made in sufficient time for inclusion in the Annual Report of the Council.

Royal Society of New South Wales

OFFICERS FOR 1967-1968

NOTICE

The Royal Society of New South Wales originated in 1821 as the " Philosophical Society of Australasia " ; after an interval of inactivity it was resuscitated in 1850 under the name of the " Australian Philosophical Society ", by which title it was known until 1856, when the name was changed to the " Philosophical Society of New South Wales ". In 1866, by the sanction of Her Most Gracious Majesty Queen Victoria, the Society assumed its present title, and was incorporated by Act of Parliament of New South Wales in 1881.

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NOTICE TO AUTHORS

General. Manuscripts should be addressed to the Honorary Secretaries, Royal Society of New South Wales, 157 Gloucester Street, Sydney. Two copies of each manuscript are required: the original typescript and a carbon copy; together with two additional copies of the abstract typed on separate sheets.

Papers should be prepared according to the general style adopted in this Journal. They should be as concise as possible, consistent with adequate presentation. Particular attention should be given to clarity of expression and good prose style.

The typescript should be double-spaced, preferably on quarto paper, with generous side margins. Headings should be typed without underlining; if a paper is long, the headings should also be given in a table of contents typed on a separate sheet, for the guidance of the Editor.

The approximate positions of Figures, Plates and Tables should be indicated in the text between parallel ruled lines. Captions of Figures and Plates should be typed on a separate sheet.

The author's institutional or residential address should be given in the title of the paper, the relevant author's initials being attached in brackets to the appropriate address in cases of papers written jointly.

Abstract. An *informative* abstract should be provided at the commencement of each paper for the guidance of readers and for use in abstracting journals.

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Geological Papers. Except in special circumstances, authors submitting manuscripts in which new stratigraphical nomenclature is proposed must also submit the letter of approval of or comment on the new names from the appropriate nomenclature sub-committee of the Geological Society of Australia.

Reprints. Authors who are members of the Society receive 25 copies of each paper free. Additional copies may be purchased provided they are ordered by the author when returning galley-proofs.

THE AUTHORS OF PAPERS ARE ALONE RESPONSIBLE FOR THE STATEMENTS MADE AND THE OPINIONS EXPRESSED THEREIN.

Journal and Proceedings, Royal Society of New South Wales, Vol. 101, pp. 65–71, 1968

Precise Observations of Minor Planets at Sydney Observatory during 1965 and 1966

W. H. Robertson

The programme of precise observations of selected minor planets which was begun in 1955 is being continued and the results for 1965 and 1966 are given here. The methods of observation and reduction were described in the first paper (Robertson, 1958). All the plates were taken with the 23 cm. camera (scale 116 ″ to the millimetre). Four exposures were made on each plate.

In Table I are given the means for all four images for the separate groups of stars at the mean of the times. The differences between the results average $0^s{\cdot}028 \sec \delta$ in right ascension and $0''{\cdot}40$ in declination. This corresponds to probable errors for the mean of the two results from one plate of $0^s{\cdot}012 \sec \delta$ and $0''{\cdot}17$. The result from the first two exposures was compared with that from the last two by adding the movement computed from the ephemeris. The means of the differences were $0^s{\cdot}012 \sec \delta$ in right ascension and $0''{\cdot}15$ in declination. It is expected that the two results from each plate will be combined into one when they are used. However they are published in the present form so that any alteration of the positions of the reference stars can be conveniently applied by using the dependences from Table II. No correction has been applied for aberration, light time or parallax but the factors give the parallax correction when divided by the distance. The observers at the telescope were W. H. Robertson (R), K. P. Sims (S) and Harley Wood (W).

In accordance with the recommendation of Commission 20 of the International Astronomical Union, Table II gives for each observation the positions of the reference stars and the dependences. The columns headed " R.A." and " Dec." give the seconds of time and arc with proper motion correction applied to bring the catalogue position to the epoch of the plate. The column headed " Star " gives the number from the Yale Catalogue (Vols. 11, 12, 13, 14, 16, 17, 20, 21). The plates were measured by Miss R. Bull, Miss J. Doust and Miss B. Frank who have also assisted with the reductions.

Reference

Robertson, W. H., 1958. *J. Roy. Soc. N.S.W.*, **92**, 18. Sydney Observatory Papers No. 33.

Table I

No.			R.A. (1950·0) h	m	s	Dec. (1950·0) °	′	″	Parallax Factors s	″	
		1 Ceres 1965 U.T.									
673	July	05·81154	00	23	27·844	−10	35	18·08	+0·008	−3·46	S
674	July	05·81154	00	23	27·782	−10	35	17·98			
675	July	13·80071	00	27	23·096	−10	45	41·34	+0·033	−3·44	W
676	July	13·80071	00	27	23·017	−10	45	41·14			
677	July	15·78215	00	28	10·742	−10	49	36·07	−0·009	−3·43	W
678	July	15·78215	00	28	10·702	−10	49	36·20			
679	July	21·77002	00	30	07·078	−11	04	41·08	0·000	−3·39	R
680	July	21·77002	00	30	07·098	−11	04	41·96			
681	July	26·76185	00	31	10·614	−11	21	00·59	+0·015	−3·35	S
682	July	26·76185	00	31	10·594	−11	21	00·24			
683	August	09·71560	00	31	15·149	−12	23	28·93	−0·010	−3·21	R
684	August	09·71560	00	31	15·118	−12	23	28·62			
685	August	31·65207	00	22	36·912	−14	36	11·36	−0·003	−2·89	R
686	August	31·65207	00	22	36·898	−14	36	11·43			

▲

TABLE I—*continued*

No.			R.A. (1950·0) h	m	s	Dec. (1950·0) °	′	″	Parallax Factors s	″	
		1 Ceres—*continued*									
687	Sept.	15·61603	00	11	42·856	−16	06	45·82	+0·037	−2·67	W
688	Sept.	15·61603	00	11	42·914	−16	06	45·63			
689	Sept.	20·58802	00	07	36·012	−16	32	19·66	0·000	−2·60	R
690	Sept.	20·58802	00	07	36·064	−16	32	20·24			
691	Oct.	12·50649	23	50	03·882	−17	35	35·94	+0·030	−2·45	W
692	Oct.	12·50649	23	50	03·833	−17	35	37·12			
693	Oct.	21·49097	23	44	31·124	−17	34	00·38	+0·012	−2·45	R
694	Oct.	21·49097	23	44	31·054	−17	34	00·10			
695	Nov.	08·43273	23	38	26·156	−16	44	21·54	−0·004	−2·57	R
696	Nov.	08·43273	23	38	26·077	−16	44	21·92			
697	Nov.	18·40361	23	38	13·266	−15	54	09·30	−0·009	−2·70	R
698	Nov.	18·40361	23	38	13·269	−15	54	09·06			
		7 Iris 1965 U.T.									
699	May	31·77350	21	10	09·520	−12	01	41·36	+0·008	−3·26	W
700	May	31·77350	21	10	09·508	−12	01	40·44			
701	June	09·74388	21	13	00·438	−11	18	02·17	−0·014	−3·36	R
702	June	09·74388	21	13	00·398	−11	18	01·82			
703	June	15·74716	21	13	46·520	−10	52	35·97	+0·046	−3·42	S
704	June	15·74716	21	13	46·523	−10	52	35·88			
705	July	05·69467	21	09	07·554	−09	56	07·96	+0·063	−3·55	S
706	July	05·69467	21	09	07·557	−09	56	08·38			
707	July	22·61245	20	56	48·540	−09	48	04·06	−0·022	−3·57	R
708	July	22·61245	20	56	48·544	−09	48	04·45			
709	July	26·60502	20	53	02·404	−09	51	29·90	−0·003	−3·56	S
710	July	26·60502	20	53	02·348	−09	51	30·48			
711	August	09·55706	20	38	47·832	−10	16	24·92	−0·003	−3·50	R
712	August	09·55706	20	38	47·830	−10	16	24·88			
713	August	17·55516	20	30	53·993	−10	36	50·44	+0·076	−3·46	S
714	August	17·55516	20	30	53·973	−10	36	49·40			
715	August	23·52342	20	25	38·266	−10	53	21·80	+0·040	−3·42	W
716	August	23·52342	20	25	38·264	−10	53	21·74			
717	August	31·48326	20	19	55·716	−11	15	26·07	−0·005	−3·36	R
718	August	31·48326	20	19	55·668	−11	15	24·90			
719	Sept.	14·43689	20	14	37·264	−11	48	42·21	−0·019	−3·28	R
720	Sept.	14·43689	20	14	37·301	−11	48	41·92			
721	Sept.	23·41498	20	14	42·618	−12	03	32·90	−0·011	−3·25	W
722	Sept.	23·41498	20	14	42·606	−12	03	33·21			
723	Oct.	06·39631	20	19	40·014	−12	12	25·12	+0·033	−3·24	S
724	Oct.	06·39631	20	19	39·982	−12	12	24·66			
725	Oct.	12·38625	20	23	43·859	−12	10	41·18	+0·042	−3·23	R
726	Oct.	12·38625	20	23	43·883	−12	10	40·94			
		11 Parthenope 1965 U.T.									
727	March	01·72257	14	04	56·372	−06	12	52·50	−0·007	−4·05	W
728	March	01·72257	14	04	56·334	−06	12	52·88			
729	March	10·70067	14	03	43·932	−05	40	53·80	+0·004	−4·14	R
730	March	10·70067	14	03	43·922	−05	40	54·35			
731	March	23·66026	13	58	13·513	−04	37	15·03	+0·001	−4·26	W
732	March	23·66026	13	58	13·566	−04	37	14·64			
733	April	20·56286	13	35	44·018	−01	52	21·52	−0·016	−4·62	R
734	April	20·56286	13	35	44·023	−01	52	21·38			
735	April	27·55678	13	29	34·403	−01	17	40·44	+0·038	−4·70	S
736	April	27·55678	13	29	34·364	−01	17	40·56			
737	May	04·52854	13	23	56·711	−00	50	02·96	+0·021	−4·76	W
738	May	04·52854	13	23	56·722	−00	50	02·84			
739	May	17·47233	13	15	52·037	−00	21	37·32	−0·025	−4·82	R
740	May	17·47233	13	15	52·030	−00	21	37·90			
741	May	26·44784	13	12	34·512	−00	20	37·84	−0·018	−4·82	R
742	May	26·44784	13	12	34·506	−00	20	37·88			
743	June	01·43211	13	11	32·575	−00	28	21·44	−0·014	−4·80	R
744	June	01·43211	13	11	32·573	−00	28	21·86			

TABLE I—*continued*

No.			R.A. (1950·0) h	m	s	Dec. (1950·0) °	′	″	Parallax Factors s	″	
		11 Parthenope—*continued*									
745	July	01·37447	13	19	53·248	−02	32	09·88	+0·043	−4·54	W
746	July	01·37447	13	19	53·216	−02	32	10·34			
747	July	15·34153	13	30	24·600	−04	06	11·70	+0·037	−4·33	R
748	July	15·34153	13	30	24·602	−04	06	11·68			
		2 Pallas 1966 U.T.									
749	July	26·78892	01	20	47·134	+02	14	00·04	−0·010	−5·17	W
750	July	26·78892	01	20	47·170	+02	13	59·64			
751	August	04·77095	01	25	08·183	+01	09	04·57	+0·001	−5·03	R
752	August	04·77095	01	25	08·179	+01	09	04·22			
753	August	08·76919	01	26	37·386	+00	34	32·70	+0·026	−4·96	S
754	August	08·76919	01	26	37·401	+00	34	33·44			
755	August	22·71912	01	29	20·961	−01	54	21·41	−0·012	−4·64	R
756	August	22·71912	01	29	20·962	−01	54	21·30			
757	Sept.	06·67632	01	27	38·178	−05	20	56·44	−0·018	−4·18	S
758	Sept.	06·67632	01	27	38·204	−05	20	56·24			
759	Sept.	19·64275	01	22	12·690	−08	49	13·54	−0·001	−3·71	R
760	Sept.	19·64275	01	22	12·656	−08	49	14·04			
761	Sept.	27·62315	01	17	18·596	−11	02	31·94	+0·017	−3·40	S
762	Sept.	27·62315	01	17	18·554	−11	02	32·70			
763	Oct.	10·58137	01	07	42·524	−14	29	54·70	+0·018	−2·90	R
764	Oct.	10·58137	01	07	42·546	−14	29	54·20			
765	Oct.	20·54901	00	59	54·634	−16	48	06·90	+0·020	−2·57	S
766	Oct.	20·54901	00	59	54·630	−16	48	06·88			
767	Nov.	15·46577	00	44	41·138	−20	27	31·26	+0·014	−2·03	W
768	Nov.	15·46577	00	44	41·038	−20	27	31·18			
		11 Parthenope 1966 U.T.									
769	July	11·77308	00	06	26·645	−02	35	02·69	−0·026	−4·55	R
770	July	11·77308	00	06	26·633	−02	35	02·28			
771	July	26·75282	00	15	10·002	−02	28	51·42	+0·019	−4·57	W
772	July	26·75282	00	15	10·068	−02	28	51·52			
773	August	08·70256	00	17	58·810	−02	58	07·42	−0·031	−4·50	S
774	August	08·70256	00	17	58·776	−02	58	08·34			
775	August	22·67774	00	15	34·006	−04	05	42·02	+0·014	−4·35	R
776	August	22·67774	00	15	33·978	−04	05	42·37			
777	Sept.	06·62436	00	07	13·322	−05	48	47·84	−0·007	−4·12	S
778	Sept.	06·62436	00	07	13·304	−05	48	47·80			
779	Sept.	19·58118	23	56	51·206	−07	25	32·32	−0·008	−3·90	R
780	Sept.	19·58118	23	56	51·202	−07	25	31·94			
781	Oct.	20·49010	23	35	42·000	−09	47	15·37	+0·017	−3·57	S
782	Oct.	20·49010	23	35	42·024	−09	47	15·53			
783	Nov.	15·41903	23	35	32·236	−09	07	54·54	+0·017	−3·67	W
784	Nov.	15·41903	23	35	32·250	−09	07	54·60			
		40 Harmonia 1966 U.T.									
785	June	01·75792	20	55	37·249	−18	52	43·86	−0·003	−2·25	R
786	June	01·75792	20	55	37·250	−18	52	44·20			
787	June	16·71747	20	58	50·555	−19	20	23·00	−0·008	−2·19	W
788	June	16·71747	20	58	50·572	−19	20	24·46			
789	June	20·70488	20	58	31·138	−19	33	29·28	−0·013	−2·15	R
790	June	20·70488	20	58	31·156	−19	33	29·53			
791	June	27·70377	20	56	42·562	−20	02	06·82	+0·050	−2·10	S
792	June	27·70377	20	56	42·546	−20	02	07·52			
793	July	11·64754	20	48	38·174	−21	16	42·60	+0·009	−1·90	R
794	July	11·64754	20	48	38·155	−21	16	42·80			
795	July	25·60917	20	35	56·077	−22	42	06·76	+0·038	−1·69	W
796	July	25·60917	20	35	56·082	−22	42	06·94			
797	August	04·57681	20	25	48·461	−23	38	19·98	+0·045	−1·55	R
798	August	04·57681	20	25	48·405	−23	38	21·14			
799	August	08·55057	20	21	53·946	−23	57	54·45	+0·003	−1·49	S
800	August	08·55057	20	21	54·014	−23	57	54·46			

Table I—*continued*

No.			R.A. (1950·0) h	m	s	Dec. (1950·0) °	′	″	Parallax Factors s	″	
		40 Harmonia—*continued*									
801	August	22·50127	20	10	24·188	−24	48	48·18	−0·008	−1·36	R
802	August	22·50127	20	10	24·220	−24	48	48·80			
803	Sept.	01·46349	20	05	30·798	−25	06	44·04	−0·032	−1·32	R
804	Sept.	01·46349	20	05	30·890	−25	06	43·60			
805	Sept.	12·44629	20	04	01·830	−25	09	43·77	+0·015	−1·31	S
806	Sept.	12·44629	20	04	01·816	−25	09	43·38			
807	Sept.	27·41151	20	08	39·607	−24	49	02·48	+0·025	−1·36	W
808	Sept.	27·41151	20	08	39·651	−24	49	01·71			
809	Oct.	05·39518	20	13	57·798	−24	27	41·03	+0·031	−1·42	S
810	Oct.	05·39518	20	13	57·769	−24	27	40·40			
811	Oct.	11·40051	20	19	04·664	−24	07	15·64	+0·092	−1·51	W
812	Oct.	11·40051	20	19	04·732	−24	07	15·08			

Table II

No.	Star	Depend.	R.A.	Dec.	No.	Star	Depend.	R.A.	Dec.
673	57	0·288671	24·715	54·61	687	40	0·458238	56·594	41·73
	76	0·439788	29·846	48·79		51	0·258996	57·735	57·64
	85	0·271542	06·060	53·59		70	0·282766	21·412	05·86
674	56	0·212724	48·904	37·40	688	36	0·249963	28·508	30·02
	75	0·496203	48·737	11·04		39	0·441758	41·057	32·86
	87	0·291073	15·907	10·66		78	0·308279	26·772	28·22
675	81	0·415412	38·547	38·74	689	7	0·381833	53·792	56·52
	97	0·288122	33·164	34·36		25	0·292764	34·842	16·69
	98	0·296466	41·493	44·54		51	0·325403	57·735	57·64
676	75	0·194240	48·736	11·04	690	9	0·235842	34·183	41·86
	90	0·516692	55·930	33·84		28	0·443218	47·064	34·80
	107	0·289068	35·335	48·70		38	0·320940	34·600	12·20
677	76	0·272952	29·846	48·79	691	8770	0·419940	37·818	15·94
	93	0·430556	58·764	57·00		8787	0·239914	22·724	29·32
	108	0·296491	51·685	28·78		9948	0·340145	51·274	16·47
678	81	0·308198	38·547	38·74	692	9930	0·363094	58·852	43·30
	98	0·467330	41·493	44·54		8778	0·439031	10·572	27·15
	107	0·224471	35·335	48·70		8797	0·197875	01·084	44·88
679	90	0·272273	55·931	33·85	693	9898	0·304466	05·398	58·18
	107	0·315274	35·335	48·70		8742	0·281934	34·721	13·46
	108	0·412454	51·685	28·78		8770	0·413599	37·819	15·94
680	88	0·233834	38·319	28·26	694	8735	0·374544	18·335	00·97
	97	0·417666	33·164	34·37		8778	0·221586	10·573	27·16
	116	0·348500	19·924	08·96		9912	0·403869	56·619	13·41
681	90	0·397071	55·933	33·85	695	8720	0·500423	08·601	02·78
	111	0·253868	30·927	31·91		8722	0·288221	38·422	53·42
	115	0·349061	18·492	20·18		8742	0·211356	34·720	13·46
682	88	0·267248	38·319	28·26	696	8713	0·327801	48·814	19·76
	107	0·230272	35·335	48·70		8725	0·321552	59·438	04·88
	113	0·502480	51·497	01·77		8735	0·350647	18·335	00·97
683	99	0·401848	48·146	57·96	697	8705	0·309191	21·445	58·75
	102	0·284358	27·046	06·93		8726	0·346488	20·483	04·36
	118	0·313794	01·595	52·26		8737	0·344320	26·658	25·53
684	88	0·372826	38·319	28·26	698	8715	0·383203	02·330	29·62
	106	0·266076	18·166	58·59		8728	0·430345	30·315	39·37
	122	0·361099	42·841	39·65		8739	0·186452	48·555	38·31
685	89	0·236224	39·885	33·95	699	7500	0·340555	51·060	42·30
	96	0·360646	32·399	08·90		7525	0·432522	11·349	41·05
	128	0·403130	12·277	15·29		7536	0·226923	09·370	03·14
686	86	0·290580	14·541	31·98	700	7515	0·490044	37·361	16·84
	110	0·394862	32·930	16·51		7520	0·279356	19·281	31·67
	131	0·314558	44·116	11·46		7523	0·230600	05·977	18·57

Table II—*continued*

No.	Star	Depend.	R.A.	Dec.
701	7519	0·318395	03·651	02·49
	7528	0·295928	28·657	56·35
	7556	0·385677	36·486	13·16
702	7523	0·346615	05·977	18·57
	7533	0·318298	43·978	30·90
	7547	0·335087	13·907	30·81
703	7519	0·403124	03·651	02·49
	7545	0·313397	38·430	09·68
	7567	0·283478	06·580	44·99
704	7520	0·222994	19·281	31·67
	7522	0·359816	58·180	07·74
	7566	0·417190	03·022	59·65
705	7508	0·330046	02·268	50·43
	7511	0·360076	32·113	57·68
	7522	0·309878	58·180	07·74
706	7494	0·237168	30·069	16·43
	7531	0·317514	41·847	24·04
	7600	0·445318	30·890	36·80
707	7413	0·300648	11·355	51·63
	7451	0·383288	38·913	24·02
	7517	0·316064	51·297	00·73
708	7415	0·332572	11·267	39·82
	7458	0·283278	05·022	20·60
	7525	0·384151	39·975	25·18
709	7391	0·299062	02·225	16·31
	7413	0·318054	11·355	51·63
	7511	0·382884	25·593	10·73
710	7388	0·429242	17·865	19·72
	7423	0·248068	24·334	25·87
	7427	0·322690	12·162	37·59
711	7307	0·305592	09·594	11·39
	7322	0·314690	01·833	27·70
	7331	0·379718	43·706	22·90
712	7298	0·378390	48·803	30·50
	7328	0·241060	32·694	22·04
	7340	0·380550	38·921	31·28
713	7248	0·329132	21·235	14·68
	7261	0·362110	37·420	13·20
	7287	0·308758	56·162	20·83
714	7237	0·303586	52·348	10·28
	7271	0·379685	46·339	18·91
	7286	0·316729	43·001	42·05
715	7210	0·271482	25·797	16·23
	7222	0·429626	08·544	52·03
	7248	0·298892	21·232	14·68
716	7205	0·266947	41·466	36·48
	7225	0·439554	34·766	46·20
	7249	0·293499	24·359	34·49
717	7162	0·322819	14·760	38·01
	7192	0·233623	07·145	42·19
	7193	0·443558	15·209	24·87
718	7163	0·356175	17·408	10·42
	7183	0·307879	57·691	42·71
	7205	0·335946	41·469	36·48
719	7124	0·343598	02·409	27·43
	7147	0·329152	11·455	03·37
	7177	0·327250	48·729	20·32
720	7130	0·306596	03·893	35·06
	7150	0·430792	50·663	23·95
	7162	0·262612	14·761	38·01
721	7137	0·452545	04·986	11·16
	7150	0·276510	50·663	23·95
	7163	0·270944	17·408	10·42
722	7124	0·351584	02·409	27·43
	7156	0·331228	10·258	48·20
	7162	0·317188	14·761	38·01
723	7177	0·441044	48·729	20·32
	7180	0·337951	49·978	33·79
	7192	0·221006	07·148	42·18
724	7158	0·331580	39·763	41·20
	7175	0·329882	42·560	59·65
	7212	0·338538	32·301	52·21
725	7180	0·216517	49·979	33·79
	7210	0·456632	25·797	16·23
	7236	0·326850	44·269	32·28
726	7192	0·300872	07·147	42·18
	7208	0·232734	57·269	03·20
	7228	0·466394	48·160	45·95
727	4998	0·378780	20·168	09·12
	5022	0·218333	05·152	46·96
	5038	0·402887	50·953	27·25
728	5013	0·439532	35·340	41·68
	5040	0·237424	54·330	19·77
	5021	0·323043	18·933	26·70
729	5016	0·375200	00·801	24·50
	5022	0·259276	05·152	46·96
	5024	0·365523	14·807	37·03
730	5006	0·359952	21·182	14·56
	5023	0·394371	15·011	33·91
	5038	0·245677	50·953	27·25
731	4981	0·176882	08·747	27·08
	5000	0·334100	06·661	33·04
	5001	0·489017	05·749	31·19
732	4987	0·263308	22·229	35·65
	4996	0·558879	14·252	10·84
	5019	0·177813	25·147	47·67
733	3609	0·296558	59·675	42·52
	3615	0·361347	21·476	13·19
	3624	0·342096	38·285	07·21
734	3605	0·339118	13·660	58·26
	3610	0·354316	09·629	21·97
	3626	0·306566	19·476	00·76
735	3589	0·243036	08·702	06·74
	3593	0·432365	10·753	55·42
	3597	0·324598	10·050	07·29
736	3583	0·404154	21·643	44·60
	3595	0·283376	02·114	29·56
	3606	0·312470	18·455	35·57
737	3569	0·387916	46·185	13·94
	3580	0·336146	55·463	06·09
	3586	0·275938	12·960	21·42
738	3572	0·291323	40·052	49·60
	3577	0·507938	10·977	40·15
	3593	0·200739	10·753	55·42
739	3557	0·405513	49·027	33·55
	3559	0·232266	52·858	16·27
	3568	0·362220	54·873	04·26
740	3552	0·296998	32·077	27·19
	3563	0·415542	24·272	23·89
	3566	0·287460	34·026	35·36
741	3541	0·172808	10·555	47·41
	3557	0·555700	49·027	33·55
	3559	0·271491	52·858	16·27
742	3546	0·241704	33·918	46·44
	3553	0·505264	37·132	39·99
	3563	0·253032	24·271	23·90
743	3538	0·324084	20·383	16·06
	3553	0·401994	37·132	39·99
	3563	0·273922	24·271	23·90
744	3541	0·392147	10·555	47·41
	3557	0·343300	49·027	33·55
	3559	0·264553	52·858	16·27

TABLE II—*continued*

No.	Star	Depend.	R.A.	Dec.	No.	Star	Depend.	R.A.	Dec.
745	4815	0·331268	46·521	03·93	767	172	0·236152	25·094	08·58
	4844	0·245879	26·883	09·30		195	0·437828	12·046	07·27
	3574	0·422853	49·343	13·79		214	0·326020	26·333	54·52
746	3561	0·364569	20·483	08·38	768	183	0·342006	22·816	35·60
	3576	0·375163	39·135	55·90		199	0·225501	41·929	33·09
	4833	0·260268	52·081	56·46		206	0·432493	29·435	52·24
747	4864	0·343478	09·494	00·04	769	5	0·426172	56·690	55·58
	4879	0·355560	33·236	20·34		24	0·340767	10·189	25·80
	4888	0·300961	48·669	43·24		41	0·233061	46·799	46·22
748	4861	0·306515	07·402	53·76	770	13	0·361256	38·083	36·11
	4875	0·229185	40·664	32·09		17	0·228162	11·939	37·06
	4890	0·464300	56·419	05·90		31	0·410582	43·667	19·38
749	365	0·212358	45·172	32·21	771	42	0·440274	50·929	32·40
	380	0·366716	02·569	28·15		61	0·266837	59·088	24·09
	388	0·420926	05·514	10·88		65	0·292889	29·927	43·24
750	360	0·285815	19·969	08·75	772	46	0·313418	54·860	03·99
	369	0·293594	43·488	11·23		51	0·474386	31·952	51·20
	399	0·420591	33·166	12·49		72	0·212196	54·985	04·09
751	262	0·199146	52·060	22·23	773	54	0·237824	59·126	41·70
	278	0·523386	11·978	12·07		58	0·311521	44·883	32·78
	406	0·277469	11·654	28·97		77	0·450655	06·307	02·16
752	261	0·188580	40·392	54·98	774	59	0·400268	59·055	54·17
	285	0·344867	21·968	07·80		65	0·255918	29·927	43·24
	399	0·466553	33·166	12·49		72	0·343814	54·985	04·09
753	268	0·265520	45·644	04·30	775	46	0·273216	54·862	03·98
	275	0·315690	50·014	04·92		52	0·471240	42·341	37·58
	294	0·418790	25·250	53·27		73	0·255544	59·532	40·28
754	263	0·274238	24·258	31·22	776	39	0·244751	53·988	29·30
	287	0·481893	34·650	03·50		54	0·445947	59·127	41·70
	288	0·243869	37·943	36·84		74	0·309302	05·843	58·02
755	333	0·232202	23·090	56·30	777	8	0·379268	14·236	52·94
	362	0·425794	13·905	19·77		21	0·317136	51·436	03·75
	286	0·342004	27·193	45·38		25	0·303596	02·234	47·67
756	277	0·309374	06·846	45·34	778	18	0·257548	19·186	58·81
	346	0·378663	43·350	24·59		14	0·462011	12·127	12·02
	368	0·311963	19·133	48·09		32	0·280441	38·798	11·95
757	300	0·265862	30·192	33·13	779	8428	0·255228	51·501	35·95
	337	0·381474	55·221	46·22		8446	0·416084	33·180	38·55
	347	0·352664	15·849	58·94		8458	0·328688	50·643	14·95
758	331	0·318760	17·234	38·45	780	8433	0·344514	27·531	56·72
	360	0·317306	08·768	24·79		8448	0·428618	03·819	32·62
	298	0·363935	45·503	08·43		8449	0·226868	12·038	16·78
759	277	0·473978	08·676	08·49	781	8229	0·213300	41·051	56·95
	296	0·214348	58·244	12·24		8240	0·393014	40·217	40·89
	297	0·311674	58·584	21·63		8363	0·393685	21·889	03·05
760	276	0·400778	54·713	48·88	782	8217	0·350268	35·327	28·18
	307	0·279398	41·068	58·46		8244	0·328284	53·995	16·78
	295	0·319824	33·520	20·41		8372	0·321448	01·412	07·28
761	257	0·215010	39·176	48·87	783	8357	0·459250	49·162	15·95
	272	0·481521	22·077	13·51		8372	0·246465	01·411	07·28
	281	0·303469	06·045	35·36		8238	0·294284	18·078	09·12
762	254	0·303772	18·585	25·46	784	8348	0·364183	27·364	51·38
	265	0·255728	28·361	13·82		8375	0·412682	47·945	20·13
	291	0·440500	07·730	56·58		8229	0·223135	41·052	56·95
763	273	0·403210	11·149	11·64	785	8973	0·309006	52·386	58·50
	289	0·194504	22·816	33·71		8998	0·293269	15·354	23·35
	291	0·402286	25·835	11·66		9009	0·397724	17·051	17·87
764	268	0·383166	57·012	45·41	786	8965	0·262362	51·623	27·85
	293	0·311550	36·351	30·61		8996	0·530258	08·243	54·92
	296	0·305284	29·494	58·46		9015	0·207380	03·941	13·02
765	249	0·295762	38·850	32·65	787	8984	0·238214	38·550	45·25
	258	0·144476	00·912	33·88		9027	0·530760	07·276	26·26
	261	0·559762	04·731	45·56		9028	0·231025	14·582	08·99
766	243	0·238450	57·789	16·04	788	8995	0·339502	51·633	31·73
	259	0·325862	53·465	40·49		9015	0·212580	03·941	13·02
	262	0·435688	20·123	07·15		9033	0·447918	00·205	02·97

TABLE II—*continued*

No.	Star	Depend.	R.A.	Dec.	No.	Star	Depend.	R.A.	Dec.
789	9006	0·355428	06·294	12·83	801	14035	0·397517	01·471	42·27
	9009	0·208444	17·052	17·87		14043	0·329714	49·500	16·13
	9029	0·436128	15·633	04·88		14067	0·272769	06·600	15·30
790	8985	0·208114	44·303	05·69	802	14030	0·394132	16·280	02·63
	9014	0·493392	36·400	51·08		14054	0·237536	09·946	02·17
	9033	0·298494	00·205	02·96		14061	0·368332	11·670	02·15
791	8991	0·221354	07·691	35·79	803	13980	0·206309	13·375	04·76
	9006	0·269401	06·294	12·83		14003	0·331430	21·250	07·79
	9007	0·509245	11·264	32·79		14023	0·462261	05·891	27·76
792	8979	0·290184	58·289	32·71	804	13986	0·268424	56·115	39·26
	9020	0·364240	26·447	58·81		13989	0·392890	35·192	16·23
	8996	0·345576	08·244	54·92		14042	0·338686	47·463	19·74
793	8921	0·354800	26·646	13·24	805	13961	0·330856	46·245	09·24
	8945	0·280686	55·244	36·20		13986	0·233771	56·115	39·26
	8961	0·364514	31·498	13·38		14023	0·435372	05·891	27·76
794	8929	0·271220	22·028	55·47	806	13965	0·304108	55·104	17·15
	8953	0·391183	15·979	53·61		13989	0·370481	35·192	16·23
	14462	0·337596	34·185	33·51		14024	0·325411	27·183	23·13
795	14314	0·241993	07·704	31·38	807	14020	0·314816	02·555	54·92
	14324	0·549054	52·959	44·58		14035	0·348052	01·471	42·27
	14333	0·208953	00·361	13·29		14042	0·337133	47·463	19·74
796	14299	0·256706	28·023	07·82	808	14003	0·424997	21·250	07·79
	14320	0·402438	31·614	07·03		14043	0·265498	49·500	16·13
	14353	0·340856	16·747	02·05		14062	0·309505	11·930	18·66
797	14191	0·332444	45·177	13·32	809	14062	0·498907	11·930	18·69
	14197	0·413958	12·190	47·93		14078	0·163746	46·077	51·22
	14240	0·253598	10·719	56·14		14106	0·337348	40·622	25·76
798	14178	0·500734	33·667	07·56	810	14061	0·258903	11·670	02·15
	14212	0·189479	11·243	45·28		14080	0·277580	01·894	37·02
	14250	0·309787	12·086	45·11		14085	0·463517	54·381	14·13
799	14141	0·315832	50·086	25·87	811	14124	0·350996	14·956	19·13
	14149	0·362454	41·314	20·72		14127	0·358920	24·023	38·76
	14198	0·321714	17·451	43·60		14152	0·290085	55·278	37·61
800	14127	0·235625	24·023	38·76	812	14108	0·278068	40·074	54·75
	14160	0·323483	47·514	22·51		14141	0·365589	50·086	25·87
	14181	0·440892	50·998	03·19		14144	0·356343	10·797	22·73

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Minor Planets Observed at Sydney Observatory During 1967

W. H. Robertson

The following observations of minor planets were made photographically at Sydney Observatory with the 23 cm. lens. Observations were confined to those with southern declinations in the *Ephemerides of Minor Planets* published by the Institute of Theoretical Astronomy at Leningrad.

On each plate two exposures, separated in declination by approximately 0·′5, were taken with an interval of about 20 minutes between them. The beginnings and endings of the exposures were automatically recorded on a chronograph by a contact on the shutter.

Rectangular coordinates of both images of the minor planet and three reference stars were measured in direct and reversed positions of the plate on a long screw measuring machine. The usual three star dependence reduction retaining second order terms in the differences of the equatorial coordinates was used. Proper motions when they were available, were applied to bring the star positions to the epoch of the plate. Each exposure was reduced separately in order to provide a check by comparing the difference between the two positions with the motion derived from the ephemeris. The tabulated results are means of the two positions at the average time. No correction has been applied for aberration, light time or parallax, but in Table I are given the factors which give the parallax correction when divided by the distance. The serial numbers follow on from those of a previous paper (Robertson, 1967). The observers named in Table II are W. H. Robertson (R), K. P. Sims (S) and H. W. Wood (W). The measurements were made by Miss R. Bull and Miss B. Frank, who have also assisted in the computation.

Reference

Robertson, W. H., 1967. *J. Roy. Soc. N.S.W.*, **100**, 181. Sydney Observatory Papers No. 55.

Table I

No.	Planet	U.T.	R.A. (1950·0) h m s	Dec. (1950·0) ° ′ ″	Parallax Factors s	″
2190	8	1967 May 22·68325	17 37 22·44	−17 39 20·9	+0·11	−2·5
2191	55	1967 May 03·67628	16 33 26·29	−30 10 22·7	+0·07	−0·6
2192	55	1967 May 31·56412	16 07 51·30	−30 13 45·0	0·00	−0·5
2193	58	1967 May 04·65342	16 12 05·82	−13 15 50·7	+0·04	−3·1
2194	58	1967 May 30·54226	15 50 34·56	−11 51 10·6	−0·04	−3·4
2195	64	1967 May 01·68420	16 27 48·90	−23 38 23·2	+0·09	−1·6
2196	64	1967 May 09·64940	16 21 40·84	−23 26 03·9	+0·06	−1·6
2197	70	1967 May 22·70670	18 10 42·31	−33 36 31·5	+0·12	−0·1
2198	94	1967 Aug 02·51798	18 55 05·79	−33 37 48·9	+0·04	0·0
2199	95	1967 May 17·59552	14 50 42·01	−21 07 56·7	+0·16	−2·0
2200	101	1967 May 22·65894	16 21 43·53	−38 32 24·9	+0·26	+0·3
2201	108	1967 Apr 19·55926	13 08 12·31	−10 54 06·9	+0·02	−3·4
2202	108	1967 Apr 27·52058	13 02 33·85	−10 26 24·6	−0·02	−3·5
2203	116	1967 Aug 08·55104	20 30 28·82	−23 50 23·6	−0·02	−1·5
2204	116	1967 Aug 25·48564	20 17 37·69	−24 27 26·9	−0·05	−1·4
2205	127	1967 Aug 02·54821	19 51 52·67	−33 35 14·8	+0·01	−0·2
2206	128	1967 Aug 02·61363	21 46 32·67	−22 52 51·1	−0·04	−1·7
2207	128	1967 Aug 08·62726	21 41 40·72	−23 29 39·7	+0·07	−1·6
2208	145	1967 Jul 13·52998	18 21 12·69	−30 37 40·2	−0·03	−0·5
2209	150	1967 Aug 08·52305	19 34 32·11	−18 16 08·3	+0·02	−2·3
2210	150	1967 Aug 15·48949	19 30 16·26	−18 30 37·8	−0·02	−2·3
2211	159	1967 Jul 31·66381	22 31 57·62	−11 16 28·7	0·00	−3·4
2212	159	1967 Aug 10·63080	22 26 15·09	−12 07 05·1	0·00	−3·3

TABLE I—*Continued*

No.	Planet	U.T.	R.A. (1950·0) h m s	Dec. (1950·0) ° ′ ″	Parallax Factors s	″
2213	160	1967 May 01·65328	15 35 33·46	−23 20 03·2	+0·10	−1·6
2214	160	1967 May 31·52257	15 08 41·20	−22 07 48·3	0·00	−1·8
2215	163	1967 Apr 18·58100	13 53 29·74	−05 11 14·6	−0·02	−4·2
2216	209	1967 May 29·67668	18 32 09·66	−33 39 59·3	+0·03	0·0
2217	209	1967 Jul 11·51855	17 55 45·39	−34 06 52·4	−0·03	+0·1
2218	211	1967 May 30·57062	16 23 21·91	−23 08 05·5	−0·02	−1·6
2219	237	1967 Aug 01·53770	19 28 11·29	−30 30 45·4	+0·02	−0·5
2220	266	1967 May 30·60734	17 12 08·28	−16 19 21·7	−0·01	−2·6
2221	292	1967 Jul 12·58314	18 53 58·54	−44 53 34·6	+0·08	+1·7
2222	332	1967 Jul 12·54583	18 42 08·36	−27 32 55·0	−0·03	−1·0
2223	334	1967 May 04·61568	14 57 07·68	−10 12 11·1	+0·09	−3·5
2224	334	1967 May 17·54317	14 48 46·16	−09 37 35·8	−0·01	−3·6
2225	356	1967 Apr 27·54722	13 28 59·21	−16 41 04·6	+0·01	−2·6
2226	356	1967 May 04·53986	13 23 14·98	−16 14 50·4	+0·06	−2·6
2227	364	1967 Aug 08·59907	21 21 44·91	−21 17 17·9	+0·02	−1·9
2228	364	1967 Aug 31·49557	20 59 39·27	−23 43 53·1	−0·06	−1·6
2229	366	1967 Aug 02·61363	21 51 24·09	−21 19 24·1	−0·05	−1·9
2230	382	1967 May 31·66495	18 19 18·47	−31 59 17·7	+0·04	−0·3
2231	382	1967 Jul 12·51511	17 43 38·35	−30 33 43·7	0·00	−0·5
2232	389	1967 Aug 03·60578	21 16 55·46	−08 16 44·0	+0·01	−3·8
2233	389	1967 Aug 29·47688	20 54 15·28	−09 10 15·4	−0·12	−3·7
2234	393	1967 Apr 19·55927	13 10 07·60	−11 52 48·4	+0·02	−3·3
2235	393	1967 Apr 27·52058	13 03 51·10	−10 23 49·2	−0·02	−3·5
2236	412	1967 Aug 02·64645	22 23 32·85	−23 22 25·9	−0·02	−1·6
2237	425	1967 May 09·64940	16 18 41·68	−21 15 46·6	+0·06	−1·9
2238	431	1967 Apr 18·61641	14 41 15·41	−12 58 22·8	−0·01	−3·1
2239	462	1967 May 31·60368	17 06 15·80	−20 21 40·2	0·00	−2·0
2240	478	1967 Apr 27·60037	14 00 58·48	−19 11 23·8	+0·11	−2·2
2241	478	1967 May 10·53710	13 51 52·04	−17 29 05·6	+0·04	−2·4
2242	481	1967 May 17·64145	16 52 16·71	−22 58 24·5	+0·03	−1·6
2243	486	1967 May 29·61683	17 13 23·10	−14 59 15·6	+0·01	−2·8
2244	503	1967 May 11·63088	16 36 47·81	−21 23 39·0	−0·02	−1·9
2245	506	1967 Apr 04·55386	11 45 20·76	−21 15 33·8	+0·06	−1·9
2246	506	1967 Apr 18·49950	11 35 18·68	−20 12 11·6	+0·03	−2·0
2247	519	1967 Apr 18·65326	15 21 10·83	−18 18 23·8	+0·02	−2·3
2248	519	1967 May 09·57206	15 02 37·29	−18 14 34·2	−0·02	−2·3
2249	607	1967 Apr 04·63058	13 33 20·22	−26 36 58·1	+0·06	−1·1
2250	674	1967 Jul 10·69784	21 15 01·51	−33 55 06·4	+0·12	−0·1
2251	674	1967 Aug 10·59686	20 48 38·05	−36 31 02·4	+0·13	+0·3
2252	686	1967 May 17·64145	16 53 20·23	−21 03 23·4	+0·03	−1·9
2253	701	1967 May 09·64940	16 14 30·10	−22 05 20·7	+0·07	−1·8
2254	702	1967 Jul 11·65920	20 55 42·83	−08 35 10·7	+0·03	−3·7
2255	702	1967 Aug 02·57486	20 36 58·82	−07 31 08·5	−0·01	−3·9
2256	704	1967 Apr 27·57012	13 33 14·18	−33 33 06·4	+0·08	0·0
2257	704	1967 May 03·56238	13 28 30·62	−32 54 58·1	+0·12	−0·2
2258	712	1967 Aug 03·53967	19 33 30·21	−02 20 49·2	+0·03	−4·6
2259	715	1967 Jul 13·63093	20 31 42·77	−40 35 51·9	+0·01	+1·0
2260	736	1967 Jul 13·55723	18 41 25·86	−18 28 33·2	+0·02	−2·3
2261	736	1967 Aug 01·50293	18 26 40·17	−19 56 36·1	+0·04	−2·1
2262	751	1967 Aug 01·61152	21 18 55·16	−37 50 01·2	+0·01	−0·6
2263	751	1967 Aug 29·50470	20 52 18·21	−40 30 06·4	−0·04	+1·0
2264	760	1967 May 04·57319	14 09 30·43	−33 09 40·9	+0·07	−0·1
2265	760	1967 May 11·52378	14 03 20·38	−32 43 55·5	−0·03	−0·1
2266	762	1967 May 04·57319	14 13 13·89	−33 32 10·7	+0·06	0·0
2267	762	1967 May 11·52378	14 07 27·31	−32 57 12·1	−0·04	−0·1
2268	852	1967 Apr 17·64926	14 56 48·55	−26 09 29·2	+0·05	−1·2
2269	852	1967 May 03·59320	14 33 25·54	−28 50 19·9	+0·07	−0·8
2270	952	1967 Jul 05·65016	19 42 35·14	−37 27 44·4	+0·13	+0·5
2271	952	1967 Jul 13·59078	19 34 32·40	−37 52 08·7	+0·01	+0·6
2272	967	1967 Aug 10·66276	22 54 04·35	−18 13 47·9	+0·04	−2·4
2273	1021	1967 Aug 02·61363	21 56 42·19	−23 13 28·9	−0·06	−1·6
2274	1021	1967 Aug 08·62726	21 52 25·95	−24 28 14·7	+0·05	−1·4
2275	1264	1967 May 17·59552	14 50 19·45	−20 22 08·8	+0·16	−2·1
2276	1264	1967 May 30·51143	14 41 45·24	−17 05 26·9	+0·02	−2·5
2277	1278	1967 Oct 26·56594	02 03 13·28	−07 35 37·2	−0·02	−3·9

TABLE II

No.	Comparison Stars	Dependences			
2190	Yale *12* I 6343, 6348, 6356	0·39277	0·22939	0·37784	W
2191	Yale *13* II 10373, 10387, 10401	0·26494	0·36264	0·37242	W
2192	Yale *13* II 10131, 10139, 10171	0·31589	0·29303	0·39109	R
2193	Yale *11* 5624, 5639, 5645	0·39292	0·39180	0·21528	W
2194	Yale *11* 5504, 5519, 5520	0·20523	0·67554	0·11923	R
2195	Yale *14* 11470, 11492, 11511	0·16226	0·39557	0·44217	W
2196	Yale *14* 11437, 11470, 11482	0·31095	0·31087	0·37818	R
2197	Cape *17* 9744, 9791, 9798	0·21455	0·49813	0·28732	W
2198	Cape *17* 10280, 10314, 10317	0·27873	0·45009	0·27118	R
2199	Yale *13* I 6177, 6178, 6191	0·23653	0·30117	0·46230	S
2200	Cape *18* 8094, 8121, 8139	0·38750	0·27414	0·33836	W
2201	Yale *11* 4712, 4714, 4728	0·39605	0·26375	0·34020	R
2202	Yale *16* 4700, 4717, *11* 4702	0·37761	0·24573	0·37666	S
2203	Yale *14* 14256, 14263, 14293	0·46544	0·32048	0·21407	S
2204	Yale *14* 14108, 14120, 14123	0·25888	0·37725	0·36387	S
2205	Cape *17* 10822, 10834, 10872	0·20035	0·37720	0·41245	R
2206	Yale *14* 14922, 14932, 14960	0·37417	0·28342	0·34241	R
2207	Yale *14* 14896, 14904, 14922	0·32145	0·49640	0·18215	S
2208	Cape *17* 9886, 9909, 9943	0·32471	0·33638	0·33891	R
2209	Yale *12* II 8377, 8393, 8426	0·29309	0·26307	0·44384	S
2210	Yale *12* II 8349, 8368, 8379	0·30425	0·26602	0·42972	R
2211	Yale *11* 7956, 7971, 7974	0·43090	0·34030	0·22880	R
2212	Yale *11* 7919, 7939, 7947	0·34144	0·34005	0·31851	S
2213	Yale *14* 11040, 11069, 11077	0·23909	0·46014	0·30077	W
2214	Yale *14* 10821, 10859, *13* I 6284	0·15901	0·29168	0·54931	R
2215	Yale *17* 4967, 4979, 4981	0·21166	0·37733	0·41102	R
2216	Cape *17* 10029, 10061, 10063	0·30194	0·31458	0·38348	R
2217	Cape *17* 9589, 9611, 9633	0·38526	0·34578	0·26897	R
2218	Yale *14* 11466, 11470, 11492	0·38763	0·29581	0·31656	R
2219	Cape *17* 10614, 10623, 10657	0·29236	0·28571	0·42193	R
2220	Yale *12* I 6159, 6172, 6188	0·33868	0·25049	0·41082	R
2221	SAO 229363, 229380, 229429	0·22151	0·33496	0·44353	R
2222	Yale *13* II 12175, 12212, 12227	0·30655	0·29764	0·39582	R
2223	Yale *16* 5243, 5251, 5260	0·32814	0·19733	0·47453	W
2224	Yale *16* 5203, 5206, 5224	0·31571	0·32183	0·36246	S
2225	Yale *12* I 5094, 5106, 5108	0·18583	0·29828	0·51590	S
2226	Yale *12* I 5075, 5079, 5094	0·11412	0·62360	0·26228	W
2227	Yale *13* I 9158, 9177, *14* 14749	0·27335	0·31342	0·41323	S
2228	Yale *14* 14538, 14556, 14559	0·24600	0·28361	0·47039	R
2229	Yale *13* I 9333, 9351, *14* 14980	0·31406	0·33619	0·34975	R
2230	Cape *17* 9857, 9877, 9917	0·17879	0·50491	0·31630	R
2231	Cape *17* 9425, 9454, 9456	0·34350	0·35613	0·30038	R
2232	Yale *16* 7650, 7654, 7667	0·20493	0·52866	0·26641	R
2233	Yale *16* 7488, 7502, 7525	0·27005	0·27545	0·45450	R
2234	Yale *11* 4723, 4728, 4739	0·44413	0·37526	0·18061	R
2235	Yale *16* 4700, 4717, 4702	0·09755	0·47407	0·42838	S
2236	Yale *14* 15217, 15232, 15236	0·35340	0·23358	0·41302	R
2237	Yale *13* I 6742, 6751, 6759	0·20187	0·35544	0·44269	R
2238	Yale *11* 5159, 5162, 5190	0·38210	0·32212	0·29578	R
2239	Yale *13* I 6972, 7013, *12* II 6996	0·24844	0·53934	0·21222	R
2240	Yale *12* II 5904, 5917, 5933	0·27002	0·47064	0·25933	S
2241	Yale *12* I 5198, 5222, 5228	0·28685	0·37547	0·33768	R
2242	Yale *13* I 11677, 11708, 11718	0·46579	0·30945	0·22476	S
2243	Yale *12* I 6170, 6173, 6204	0·36054	0·24106	0·39840	R
2244	Yale *13* I 6799, 6813, 6826	0·32082	0·34492	0·33426	R
2245	Yale *13* I 5127, 5153, 5156	0·45045	0·17309	0·37646	S
2246	Yale *12* II 5069, 5091, 5093	0·45961	0·13117	0·40922	R
2247	Yale *12* I 5641, 5664, *12* II 6371	0·42391	0·23249	0·34360	R
2248	Yale *12* I 5543, 5559, *12* II 6252	0·08889	0·51020	0·40092	R
2249	Yale *14* 9963, 9987, 10015	0·26063	0·31110	0·42827	S
2250	Cape *17* 11612, 11616, 11643	0·37299	0·33097	0·29604	R
2251	Cape *18* 10778, 10801, 10807	0·37575	0·35445	0·26980	S
2252	Yale *14* 6897, 6901, 6920	0·26713	0·38820	0·34467	S
2253	Yale *14* 11387, 11421, *13* I 6733	0·11083	0·31182	0·57735	R
2254	Yale *16* 7502, 7521, 7525	0·17516	0·65315	0·17168	R
2255	Yale *16* 7347, 7364, 7385	0·26198	0·44286	0·29516	R
2256	Cape *17* 6872, 6894, 6912	0·34649	0·29118	0·36233	S

TABLE II—*Continued*

No.	Comparison Stars	Dependences			
2257	Cape *17* 6837, 6841, 6852	0·37159	0·25930	0·36911	W
2258	Yale *17* 6695, 6709, 6735	0·35861	0·36492	0·27648	R
2259	SAO 230266, 230283, 230298	0·21152	0·54532	0·24316	R
2260	Yale *12* II 7838, 7875, 7894	0·33090	0·48522	0·18388	R
2261	Yale *12* II 7714, 7749, *13* I 7731	0·43179	0·04150	0·52671	R
2262	Cape *18* 11008, 11012, 11039	0·31759	0·45509	0·22732	R
2263	SAO 230412, 230430, 230450	0·18382	0·25690	0·55927	R
2264	Cape *17* 7257, 7259, 7290	0·32469	0·40690	0·26841	W
2265	Cape *17* 7171, 7199, 7214	0·41067	0·20450	0·38483	R
2266	Cape *17* 7290, 7306, 7338	0·50069	0·20502	0·29429	W
2267	Cape *17* 7214, 7251, 7259	0·30520	0·35971	0·33509	R
2268	Yale *14* 10715, 10737, 10751	0·20076	0·48607	0·31317	R
2269	Yale *13* II 9197, 9209, 9226	0·21982	0·52414	0·25604	W
2270	Cape *18* 10221, 10241, 10245	0·19687	0·37554	0·42759	W
2271	Cape *18* 10142, 10195, 10196	0·38588	0·20346	0·41066	R
2272	Yale *12* II 9650, 9669, 9672	0·28959	0·24938	0·46103	S
2273	Yale *14* 10513, 10523, 10544	0·19369	0·50437	0·30194	R
2274	Yale *14* 14970, 14989, 14992	0·29624	0·29472	0·40904	S
2275	Yale *13* I 6170, 6191, *12* II 6192	0·45831	0·19251	0·34918	S
2276	Yale *12* I 5436, 5450, 5452	0·39275	0·31241	0·29484	R
2277	Yale *16* 437, 442, 463	0·35380	0·44818	0·19803	S

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Magnetic Studies of the Canobolas Mountains, Central Western New South Wales

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Abstract—Field and laboratory magnetic investigations have been carried out on rocks of the Mt. Canobolas volcanic complex, near Orange, Central Western New South Wales. The complex consists of acid to basic lavas and pyroclastics, with some intrusives, built up on Palaeozoic rocks. The field magnetic results correlate in style and trend with the anomalies shown in existing aeromagnetic maps of the surrounding region of Palaeozoic rocks, suggesting that they largely delineate the structure of these rocks beneath the volcanic pile. Detailed laboratory investigations of the petrology, mineralogy and magnetic properties of the basalts from near Orange indicated a definite correlation between these properties. The basalts could be divided into two rock-types, titanaugite olivine basalt and olivine basalt, the first type having a stable magnetization, the second type unstable magnetization. This study has shown the need for complementary petrological studies in rock magnetic investigations.

Introduction

The Canobolas Mountains form a cluster of moderately high mountains west and south-west of the City of Orange (see Figure 1). The maximum elevation is about 4,600 feet (or 1,425 m.), whereas the surrounding peneplain has a general level of 2,800 to 3,000 feet (900 to 1,000 m.).

The stream valleys towards the centre of the mountains are youthful, while Orange itself is situated in a mature valley. This stream pattern reflects the relief in the mountains. The foot-hills are generally low and undulating, with little or no outcrop, and there is a considerable increase in relief towards the centre of the complex, where the slopes are very steep. Even on these steep slopes, however, the outcrop is not good, and this lack of readily-available fresh rock created difficulties in sampling for palaeomagnetic purposes.

In brief, the igneous complex forming the Canobolas Mountains is an accumulation of alkaline lavas and basalts (with minor intrusions) of presumed Tertiary age—the order of eruption being acid to basic. This accumulation has been built up on folded and eroded Palaeozoic rocks which vary in age from Ordovician to Devonian.

Little detailed work has been done on the complex itself. David (1890) described the Old Man Canobolas; Curran (1891) described some thin sections of rocks from just to the north of this peak; and Sussmilch and Jensen (1909) carried out a brief reconnaissance of the complex. The central portion was examined in some detail by Penrose (1948). Several authors have referred to the Canobolas complex, commenting mainly on the possible order of eruption. For example, Sussmilch (1933) considered that the Canobolas Mountains occur adjacent to (or along) a north-south scarp, and that this is an example of an implied causal relation between the alkaline rocks of

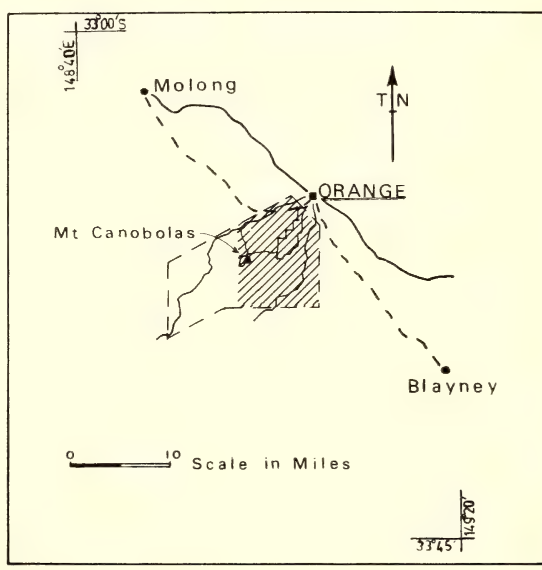

Figure 1—Locality map. Area studied is shown, with that portion described herein shaded. Geographic coordinates of Orange are: lat. 33° 17′ S., long. 149° 06′ E. Roads are shown by full lines, and railways by broken lines.

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eastern Australia and the north-south trend of the Eastern Tableland, formed by the (Pliocene) Kosciusko Uplift. This conclusion may be expanded slightly to say that the Canobolas Mountains are located at a small change in trend of the Palaeozoic rocks, this change forming a favourable locus for volcanic activity. Other references to the complex are mainly found as brief notes on the "Tertiary igneous rocks overlying the older sediments, etc.".

No definite age can be assigned to the complex, however, without the aid of radiometric dating. The only geological evidence available is in the presence of a diatomaceous earth deposit and "Cinnamomum" leaf fossils occurring at the western edge of the area studied, near Black Mountain. Although no definite relationship with the volcanics was seen, this does indicate a Tertiary age (Crespin, 1949).

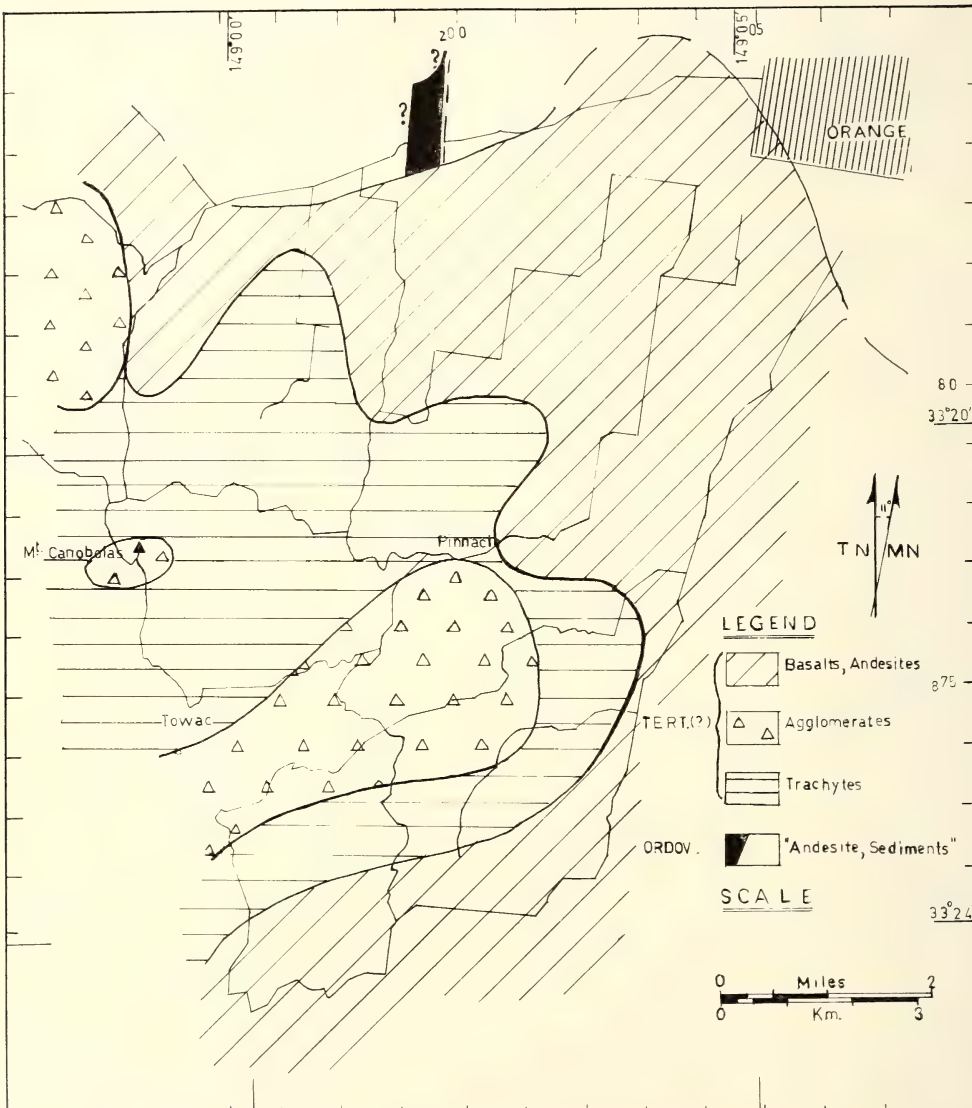

FIGURE 2—Simplified geological map of the Canobolas Mountains—showing the extrusive rocks of the complex only. The grid is taken from the Orange Military map. The major traverses are shown : ———.

In the magnetic field survey, the intensity of the vertical component " Z " of the geomagnetic field was measured. The intensity measured is not a simple intensity, but rather a sum of more than one magnetic field. There is a field induced in the rock by the earth's field, and a field " fixed " in the rock (a " remanent magnetization "). It is only recently that this second field has been considered important in magnetic field studies (e.g. Hays and Scharon, 1963 ; Strangway, 1965). The two fields are added vectorially :

$$\underset{\text{Total}}{\mathbf{J}} = \underset{\text{Remanent}}{\mathbf{J}_r} + \underset{\text{Induced}}{\mathbf{J}_i}$$

For a detailed treatment of rock magnetism, reference should be made to Nagata (1961). In keeping with recent practice, the following standard abbreviations are used in this paper : NRM (natural remanent magnetization) ; TRM (thermoremanent magnetization) ; PTRM (partial thermoremanent magnetization) ; IRM (isothermal remanent magnetization) ; VRM (viscous remanent magnetization) ; and CRM (chemical remanent magnetization).

Instruments and Methods

The field instrument used was a McPhar M500A portable fluxgate magnetometer. The field technique consisted of taking readings every 0·25 mile (0·4 km.) along roads and tracks with some closer-spaced stations surveyed on foot. Each station value was normally the average of four readings taken over an area of several square feet in order to minimize the effect of local fluctuations of the field. The whole survey was tied to a Base Station, which was used as an arbitrary datum and also as a diurnal control station and to intermediate Base Points. The field measurements were reduced by correcting for diurnal variation and by smoothing of the profiles using a five-point running average, to damp short-wavelength variations of near-surface origin :

$$V_i = \frac{1}{5} \sum_{i-2}^{i+2} v_i$$

where V_i is the smoothed value and v_i is the actual value, at the i^{th} point.

A regional correction was not applied because the field near the Bureau of Mineral Resources geomagnetic station near Orange was disturbed (Parkinson and Curedale, 1960, and field notes taken during their survey). In any case, the regional correction would only be of the order of magnitude of one contour interval over the whole area. The results were plotted on a map and contoured.

Rock samples were generally collected as the field survey was being carried out. Where possible, fresh oriented material was collected, the orientation procedure being simply to mark a strike and dip on to a face of the sample before its removal from the outcrop. Even where fresh outcrop was not available, unoriented samples were collected and the rock-type noted so as to provide correlation with the magnetic survey results. Specimens were prepared from the samples by coring in the laboratory. Orientation of the specimens during storage was random.

Since petrological and mineralogical correlation with magnetic properties was one of the main aims of the investigation, both thin sections and polished surfaces of the samples were made. In order to maintain maximum practicable control, the thin sections and polished surfaces were prepared from discs cut from the cores.

The specimens were all measured using the astatic magnetometer housed in the Old Geology Building at the University of Sydney. This instrument was designed and constructed by Kazmi (1960). The methods of measurement and reduction of readings were essentially the same as those employed by Kazmi (1960) and Manwaring (1960). For a detailed summary of palaeomagnetic theory and practice reference should be made to Irving's excellent book (1964). As yet, palaeomagnetic theory is incomplete, many assumptions being necessary and with considerable magnetic/petrological work of the type described by Wilson and Ade-Hall, and Cox, Doell and Dalrymple still necessary (e.g., Wilson, 1964 ; Ade-Hall, 1964*b* ; Cox, Doell and Dalrymple, 1964).

Because magnetizations acquired subsequent to a TRM (considering igneous rocks only here) are likely to cause a scattering in the direction of the NRM, it is necessary to remove these " secondary " magnetizations in order to determine the direction of magnetization at the time of consolidation. Two methods have been used in this present study—alternating field demagnetization and thermal demagnetization. The former method entails the application of high alternating magnetic fields to the specimen to remove " weak " magnetizations, and the latter the application of high temperatures in zero field and an inert atmosphere (e.g., nitrogen gas) to prevent oxidation of the specimen. (The attainment of an inert atmosphere is, however, difficult, because of trapped gases, and must be considered a potential limitation, especially when demagnetizing

vesicular basalts.) Thermal demagnetization has the advantage of giving an indication of the Curie temperatures of the opaque minerals—because all PTRMs acquired below a certain temperature are removed by the application of that temperature. The A.F. method was carried out using apparatus designed by Chan (1963).

A more extensive summary of the methods used may be found in Facer (1964).

Field Results

In all, 485 field stations were established along 90 miles (144 km.) over 65 square miles (166 sq. km.) of the survey. The results established a reasonable correlation between field results and surface geology in many cases—provided that these geological features were not too localized (e.g. a small dyke). A few very strong but localized anomalies were discovered, and were probably sites of lightning strikes.

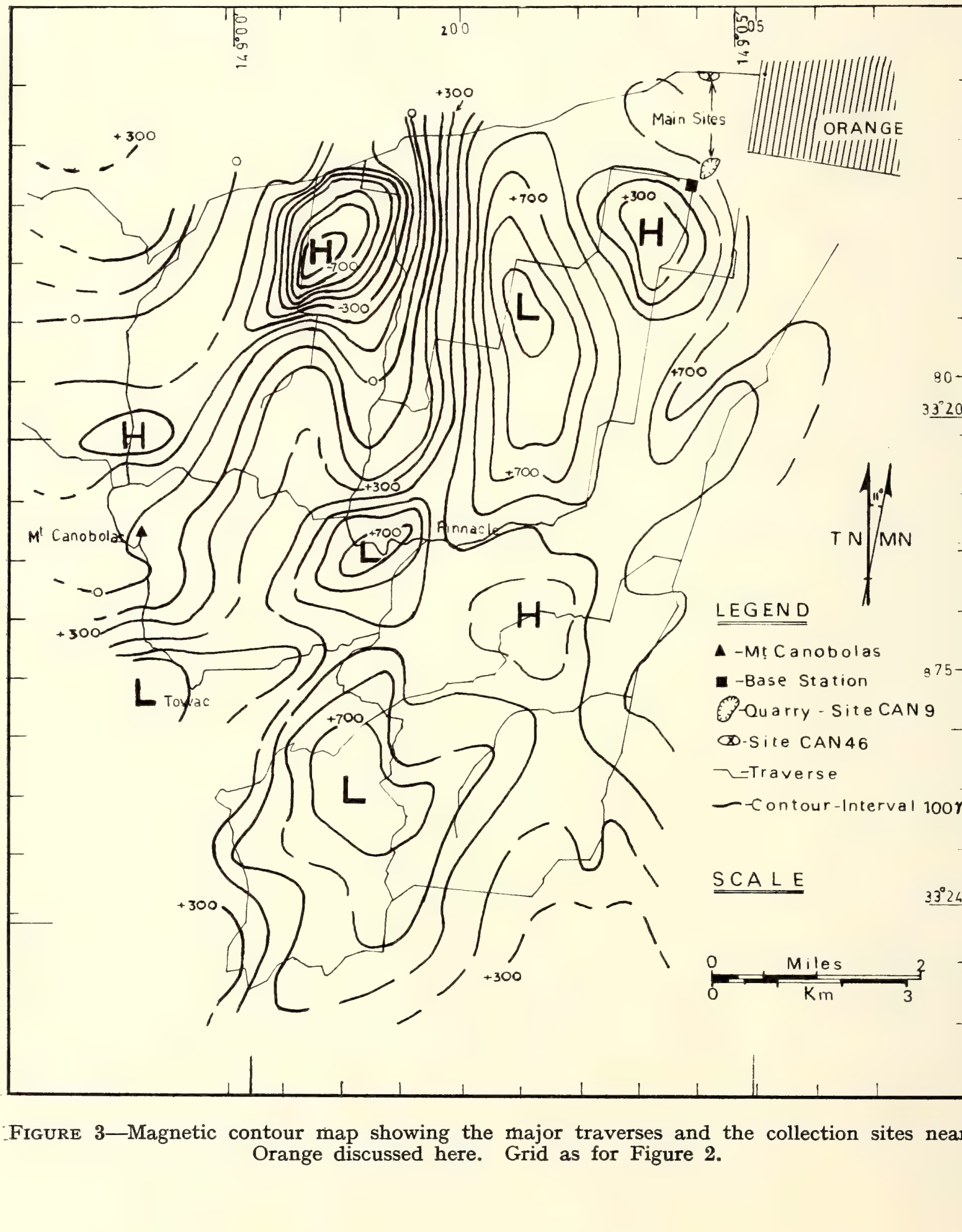

FIGURE 3—Magnetic contour map showing the major traverses and the collection sites near Orange discussed here. Grid as for Figure 2.

Figure 3 is a summary magnetic contour map of the eastern portion of the area (the western edge having been covered in a reconnaissance fashion only). The contour interval of 100γ was chosen to damp out minor fluctuations associated with strongly magnetic rocks. At the centre is a broad " Low " anomaly, divided into three more-localized Lows. Of these, the two northern Lows are associated with the central volcanic vents of the Canobolas Mountains, including Mt. Canobolas, Towac Mountain and The Pinnacle. The third (local) Low is not connected with any previously recognized igneous centre. However, it is an area of considerable agglomerate outcrop, and it is possible that this Low represents a volcano buried by the agglomerates. The two small Highs associated with this broad Low might indicate parasitic cones, or be simply normal " balancing anomalies ".

The two intense anomalies (a High and a Low) in the north of the area are probably not caused by the surface geology alone, which is basaltic, andesitic and trachytic, but are more likely to be caused by the Palaeozoic rocks of probable Ordovician age which outcrop on the northern edge of the area. The rocks strike approximately N.–S., and are altered augite-rich rock and light-coloured shales or phyllites. Southward extensions of these outcrops would place them under the main High and Low respectively. A quantitative evaluation of the remanent moment contribution at depth in the vector equation above is not possible. However, the only available outcrop provides useful clues to the possible contribution. This is likely to be considerable, especially should the " andesite " be a flow of considerable thickness, since the NRM moment of the augite-rich rock, which is probably an altered andesite, is about 1200×10^{-6} e.m.u./c.c. The phyllitic shales were unsatisfactory for preparation of specimens, but from their lithological appearance their moment is likely to be no more than one-hundredth that of the " andesite ".

To determine the depth to the body (or bodies) causing these anomalies, a profile was drawn perpendicular to the anomaly trend, and conventional depth-determination procedures carried out. These gave depths of the order of 2,000 to 4,000 feet (700 to 1,300 m.), thus showing that the surface geology has not damped the influence of the Ordovician rocks to any apparent extent.

North of the area studied the trend of the Palaeozoic rocks is N.–S., whereas to the south this trend is N.W.–S.E. This change in the regional structural trend is reflected by the magnetic contours—and the location of the volcanic centre over the change in regional trend gives further weight to the idea that the Canobolas Mountains are associated with crustal fractures, possibly opened during the Kosciusko Uplift (Sussmilch, 1933).

The sharp magnetic High near the Base Station corresponds to the outcrops of columnar basalt in this corner of the area.

Subsequent to the completion of this survey, the Bathurst 1 : 250,000 total field aeromagnetic map published by the Bureau of Mineral Resources became available. The more important features encountered in the ground survey are reflected in the air survey, although in the latter case the plane's altitude has had a damping effect. The central triangulate Low is still apparent, as is the High associated with the basalt in the north-east. More importantly, the anomalies and trends which are here considered due to the Palaeozoic basement are quite noticeable on the aeromagnetic map. One important feature of the aeromagnetic map is that the contouring of readings is made less accurate by the rather wide flight-line spacing, which at times is more than two miles. This spacing is apparently controlled by the topographic relief of the Canobolas Mountains. In an area of such localized anomalies and steep gradients as were found here, this contouring uncertainty imposes limitations on interpretation of aeromagnetic results.

Laboratory Results

The magnetic remanence of a suite of samples from localities distributed over the area was measured. The studies were only of a reconnaissance nature, and since the directions of magnetization between most samples were found to be widely scattered the results are given in summary form only in the Appendix. The scatter of magnetizations appeared to be due to IRM and, in some cases, CRM components (Kobayashi, 1959).

Only one group of laboratory results justifies detailed discussion here—those bearing upon the relationship between mineralogy/petrology and magnetic properties of some basalt samples from a small quarry near Orange.

The quarry referred to is situated adjacent to the railway line near the Base Station in the north-east corner of the area studied (Figure 3). A brief note on the petrology has already appeared (Wilshire, 1958). Wilshire considered that the quarry was situated in a

single basalt flow. The basalt in this quarry and in the surrounding outcrops is quite remarkably columnar (some columns being twisted), with columns up to 6 feet (2 m.) across—although there are patches which show little or no columnar development.

Petrological Data

Broadly speaking, the basalts can be described under two main names (titanaugite olivine basalt and olivine basalt). The modal compositions are:

	Group 1	Group 2
Plagioclase	50% (An_{50-60})	30–35% (An_{55-60})
Olivine+augite ..	30–35%	15–20%
Opaques	5–6%	15%
Glass	10% (slightly dusty)	30–35% (very dusty)

Wilshire (1958) showed that the composition of the olivines fell in the range Fo_{85-95} and the augite had 2V of 48°–50°. In the glass of Group 2 the opaque granules are arranged in strings, forming a variolitic texture. Most of the opaque content of Group 2 is concentrated as equant anhedra of titanomagnetite, with a very little ilmenite (and pyrite and chalcopyrite in CAN 9E). Group 1 opaques are present mainly as randomly-oriented, corroded (serrated) needles of ilmenite, with smaller equant anhedral to euhedral grains of magnetite and titanomagnetite.

Weathering is moderate, but the alteration of the olivine (and glass) to red and green smectite-chlorite (and patotinite and goethite) noted by Wilshire (1958, pp. 132–133) is not well developed in the thin sections studied, although, in the case of CAN 9F, the formation of magnetite from the olivine is more noticeable in the darker " column rind ", and there appears to be a higher proportion of coloured alteration products in this rind. There is a slight difference in the weathering products (when developed) of the two groups. In the first, the " serpentine " and clay/chlorite alteration products are *dark green to brown* (and red in the rind), whereas in the second there is development of a *pale green* product. In neither group is there any exsolution visible in the opaque grains—even up to magnifications of 1000×. There is a little martization visible in CAN 9A. The modal analyses for the opaques are higher than the normative values calculated from Wilshire's chemical analyses (see Table 1).

It can be seen that the Group 1 and Wilshire's unaltered basalt contain a similar percentage of opaques. The apparent higher percentage of opaques in Group 2 is not simply an overestimation from thin section study but also includes an estimate from polished surface study.

TABLE 1

Opaque Oxide Content of the Basalts

	Il-menite	(Titan) Mag-netite	Total
	%	%	%
Mode (this study), Group 1	~1	4–5	5–6
Mode (this study), Group 2	Tr.	14–15	15
Norm (calculated from Wilshire, 1958) ..	3·04	1·16	4·20
Norm (calculated from Wilshire, 1958) ..	3·19	7·89	11·08

Wilshire's analyses (his Table 4B) are of " olivine basalt " and " altered olivine basalt " respectively.

TABLE 2

Results of NRM Measurements

Sample Number	Number of Speci-mens n	Intensity of NRM $J_n \times 10^{-4}$ e.m.u./c.c.	True Direction of NRM	
			Declina-tion D° (Azimuth)	Inclina-tion I°
CAN 9A	6	14·1	088	−43
CAN 9B	3	18·7	150	−42
CAN 9C	2	11·0	148	+17
CAN 9D	6	4·91	001	−44
CAN 9E	2	3·33	187	−56
CAN 9F	6	12·2	321	−56

The magnetic susceptibilities of all samples are of the order of 10^{-4} c.g.s. units.

J_n, D and I are all averages of the n specimens. Inclination is negative when " normal " in the Southern Hemisphere.

Magnetic Data

The magnetic results are listed in Tables 2 and 3. Table 2 contains the NRM results and Table 3 the results of the two demagnetization procedures.

It can be seen in Table 2 that the directions of NRM are quite scattered—although in each case the intra-sample agreement was good, and deviated from the earth's present field direction (D=11° E., I=−64°). However, the most striking feature of this Table is the close correlation between intensity J_n of NRM and the petrography. Group 1, the (titan)augite olivine basalts all have an intensity in the range 10 to 20×10^{-4} e.m.u./c.c., whereas Group 2 (olivine basalts) have about one-third of this intensity (3 to 5×10^{-4} e.m.u./c.c.). This might

be a reflection of the opaque grain sizes in the two groups. The opaque grains in the first are mainly equant to elongate grains with sizes ranging from 0·1 to 0·5 mm., whereas the second group has only a few grains in this range, most being only approximately 5 to 15 μ, which is sufficiently large for the formation of more than one domain (Stacey (1963) notes that magnetite grains can be multidomains in the range 0·1 μ to 1000 μ).

Because of the scatter in directions, and in order to investigate the magnetic properties further, specimens from each sample were demagnetized by alternating field and thermal methods. These results are summarized in Table 3, and Figures 4 to 7. Figures 4 and 6 show the demagnetization curves for the two processes, the values having been normalized, and Figures 5 and 7 show the stereographic plots of direction relative to each sample.

TABLE 3

Stability of Magnetization

Sample Number	Estimate of Stability		Estimate of the Direction of the TRM	
	A.F.	Thermal	D° T	I°
CAN 9A	Stable	Mod. stable	112	−53
CAN 9B	Stable	Mod. stable	152	−40
CAN 9C	Stable	Mod. stable	143	+20
CAN 9D	Unstable	Unstable	*c.* 180	*c.* −51
CAN 9E	Unstable	Unstable	*c.* 114	*c.* −25
CAN 9F	Stable	Stable	015	−51

The stability is estimated from the demagnetization characteristics.

The direction is estimated from both sets of demagnetization results.

CAN 9D and CAN 9E directions are rather doubtful because of their low intensity and their instability.

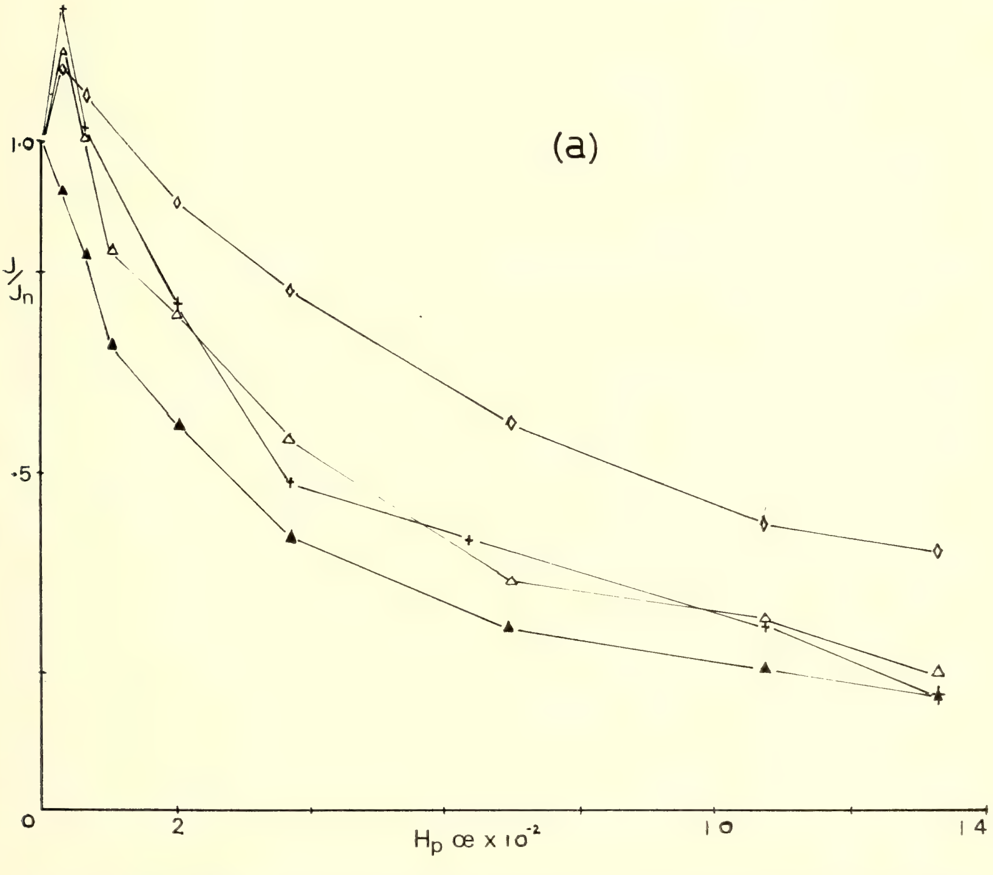

FIGURE 4 (*a*)—Alternating field demagnetization curves for the basalts from site CAN 9. H_p is the peak demagnetizing field and J/J_n is the normalized value of intensity. Group 1 : 9A (△), 9B (▲), 9C (+) and 9F (◇).

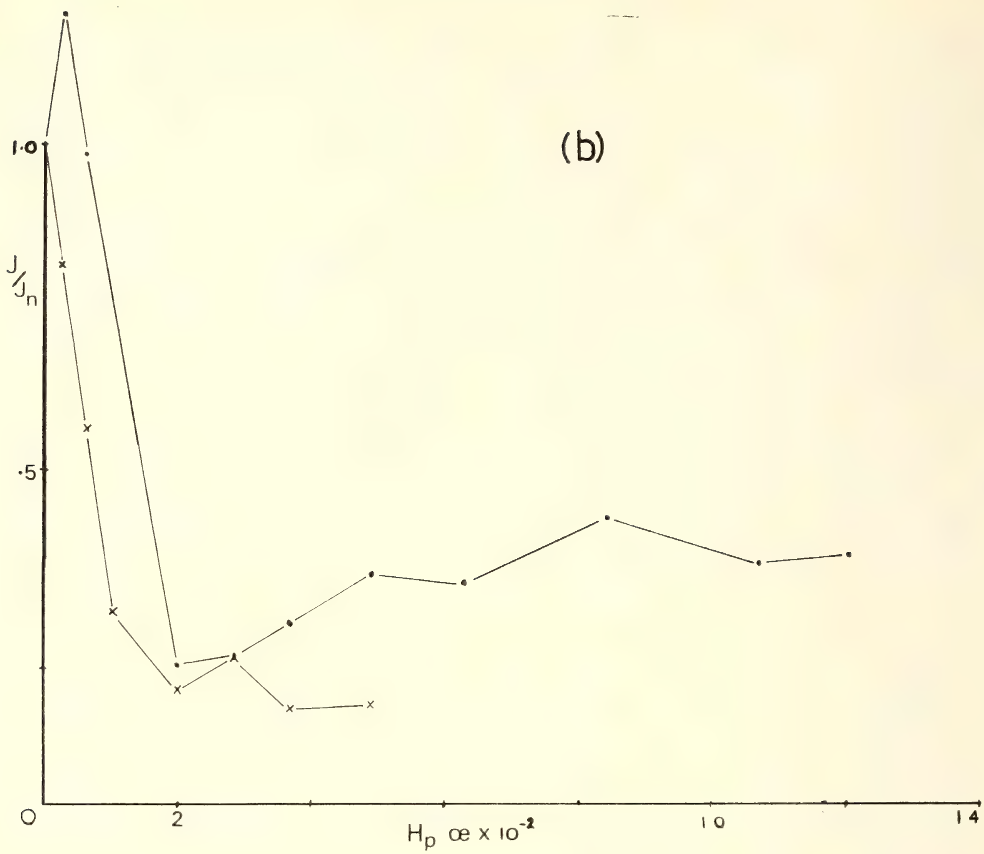

FIGURE 4 (*b*)—Alternating field demagnetization curves for the basalts from site CAN 9. H_p is the peak demagnetizing field and J/J_n is the normalized value of intensity. Group 2 : 9D (·), 9E (×).

The correlation between petrography and NRM noted above is once again obvious from the demagnetization results. The difference in magnetic properties is not due to simple differences in the extent of the weathering since care was taken in obtaining specimens away from the column rinds. If anything, weathering is very slightly more obvious in the stable Group 1 basalt.

Group 1 demagnetization curves (Figure 4) are all moderately stable insofar as they show a steady and gradual decrease after the removal of only a small secondary component probably acquired during weathering. In addition, the directions of magnetization show little variation other than slight experimental errors.

On the other hand, Group 2 results show little systematic behaviour. The demagnetization curves show a rapid decrease in J which is most likely due to VRM (and some IRM). However, the intensity then increases and decreases in a random fashion with each successive stage. In addition, the directions change rapidly—and randomly (Figure 5). Such anomalous behaviour is not an experimental coincidence, since each specimen of Group 2 was demagnetized at the same time as a specimen from Group 1.

The thermal cleaning has produced an even more noticeable difference between the groups. Up to 400° C. Group 1 directions show only a slight change (Figure 7), although after this point most of the magnetization seems to have been removed, and the remainder is more scattered in direction ; whereas the Group 2 basalts have random directions up to 400° C. Figure 6 shows that Group 1 probably contain ilmenite (Curie temperature 100° C. to 125° C.), titanomagnetite (with varying Curie temperatures due apparently to slight variations in titanium content), and a small magnetite component (550° C. to 600° C.). These mineral

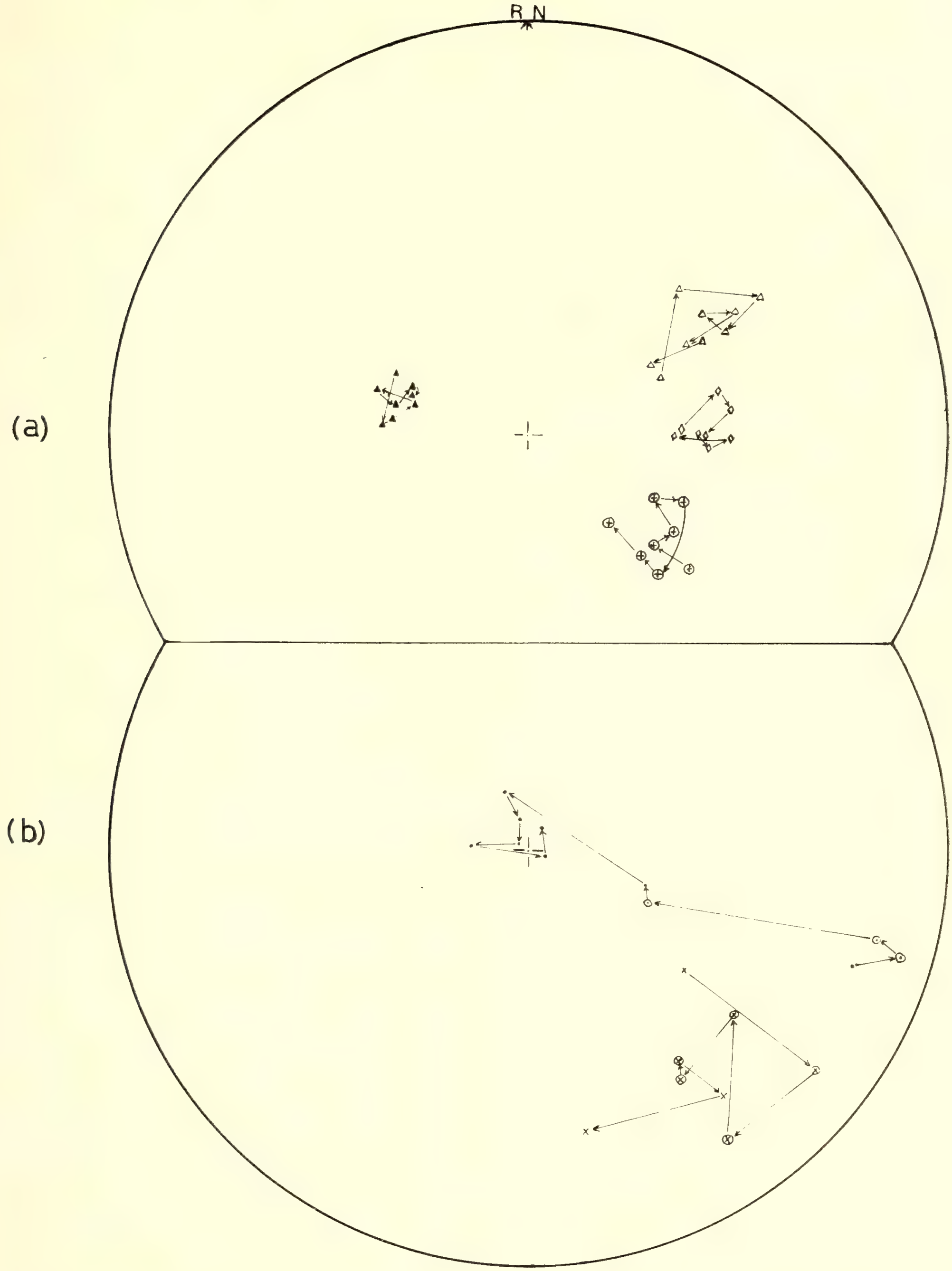

FIGURE 5—Alternating field demagnetization plots (stereographic equal-angle projection) relative to each sample for the basalts from site CAN 9. RN is relative north. Circled symbols are N-seeking directions plotted on to the Upper Hemisphere, those points not circled being plotted on to the lower hemisphere. The points correspond to those in Figure 3. Symbols as in Figure 3. (*a*) Group 1. (*b*) Group 2.

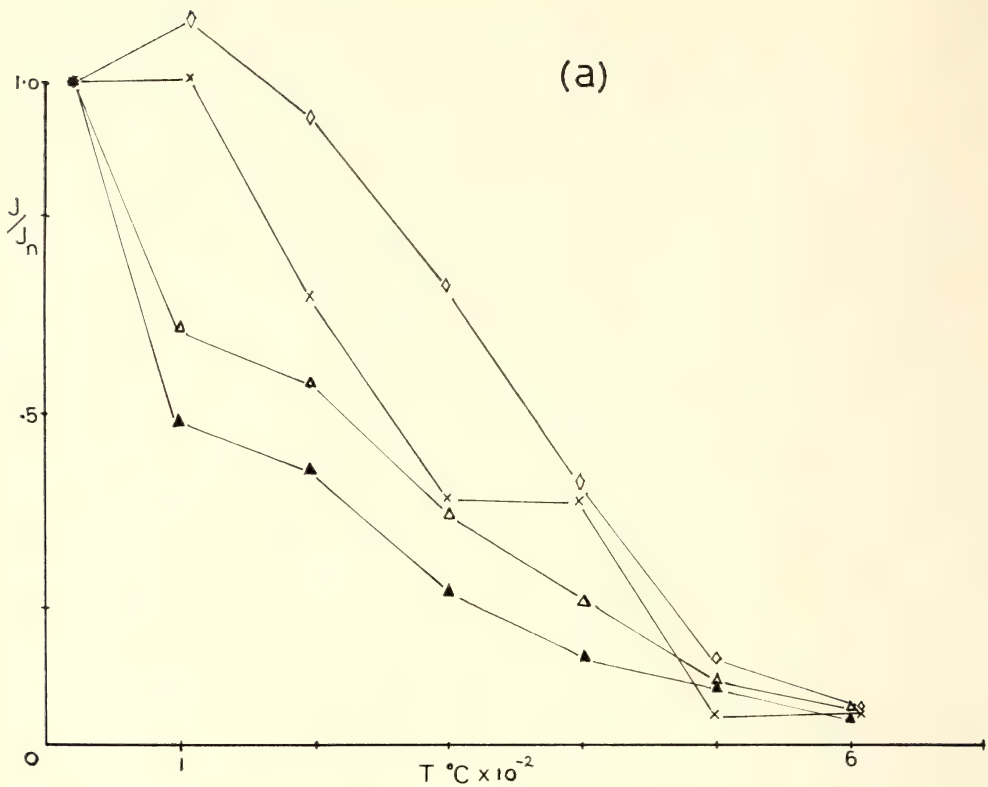

FIGURE 6 (*a*)—Thermal demagnetization curves for the basalts from site CAN 9. *T* is the demagnetizing temperature, otherwise the symbols are as in Figure 4. Group 1.

components were all detected during polished surface examination. The instability of Group 2 renders any positive estimate of the Curie temperature(s) impossible.

As a check on these results, similar work was carried out on another basalt sample collected about 1·5 miles (2·4 km.) north of the quarry. This sample was collected from a trench about 4 m. deep, dug for the laying of pipes, and the basalt appeared fresh despite a rather strong weathering rind about 2 cm. thick along the joint faces. This basalt is a (titan)augite olivine basalt with ophitic to subophitic texture, slightly porphyritic, containing about 65% plagioclase (An_{55-60}), 20% olivine and titan-augite (2V about 60°) in approximately equal proportions, 5% opaques (titanomagnetite and ilmenite) and 10% "dusty" pinkish-brown glass, and is very similar to Group 1 basalts. Weathering has produced green/brown "serpentine", clay and chlorite alteration products, mainly from the olivine and glass. As would be expected from the composition, the magnetic properties are similar to the Group 1 basalts (although the direction of magnetization does not agree). A shelf-test conducted over several months suggested stability. Figure 8 shows the A.F. demagnetization curve and plot.

It can be seen that a low coercive-force magnetic component (either due to the ilmenite or to the weathering) is first removed, and then there is a very gradual decrease in intensity indicating high stability. The stereographic plot also indicates this high stability.

Discussion

As can be seen from the present field results, subsurface structures can be readily detected if there is sufficient magnetic susceptibility and NRM contrast in the subsurface rocks, and provided some elementary precautions are taken in the survey. In particular, strong anomalies have been found over volcanic

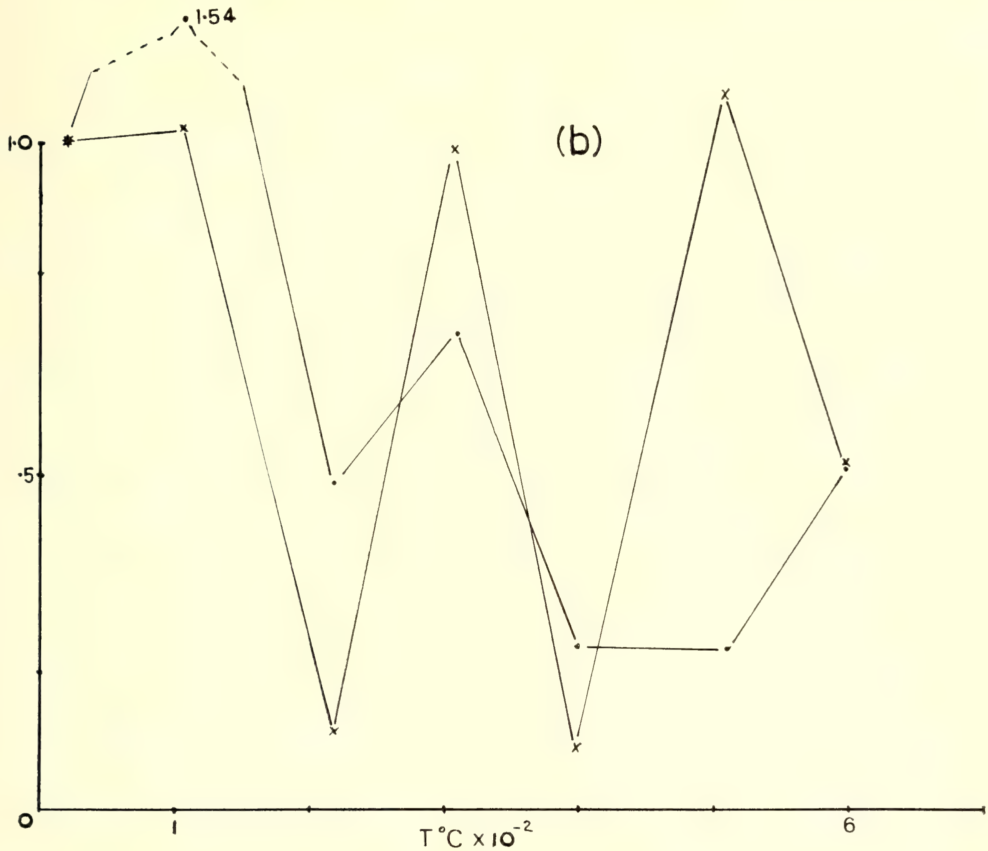

FIGURE 6 (*b*)—Thermal demagnetization curves for the basalts from site CAN 9. *T* is the demagnetizing temperature, otherwise the symbols are as in Figure 4. Group 2.

centres, and " basement " trends under a volcanic veneer have been delineated by magnetic trends.

This investigation has emphasized the close relationship between the petrological and mineralogical properties of rocks and their magnetic properties. Not only the initial composition and conditions of formation of the rock control these characteristics, but their subsequent history also seems to have an effect. In general, the relationships between the mineralogical composition and the magnetic properties is best investigated through the behaviour of the intensity and direction of magnetization during the demagnetization experiments, and this has provided good evidence here. The comparison of these demagnetization results with observations on both thin sections and polished surfaces obtained in the present investigation evidences the need for further detailed study of the correlation problem.

A more detailed study of these basalts is necessary to understand their magnetic properties fully, and the techniques employed by Ade-Hall (1964*a*, 1964*b*) and Wilson (1964) in their study of the Mull lavas in Scotland would be most useful. It is evident, for example, that there is a noticeable similarity in the weathering variations in the two areas. The Mull rocks with normal polarity showed development of pale green secondary silicates, and the reversed rocks contained dark green and brown " secondaries ". Although no polarity difference has been found in this present study, the Group 1 basalts contained dark green and brown secondary silicates, whereas the second group contained pale green alteration products only, and so they fall into the same petrographic grouping as the Mull basalts. Further, the Mull reversed lavas exhibited stable moments and the normal lavas exhibited instability (Ade-Hall and Wilson, 1963), which is exactly as detected in the Orange

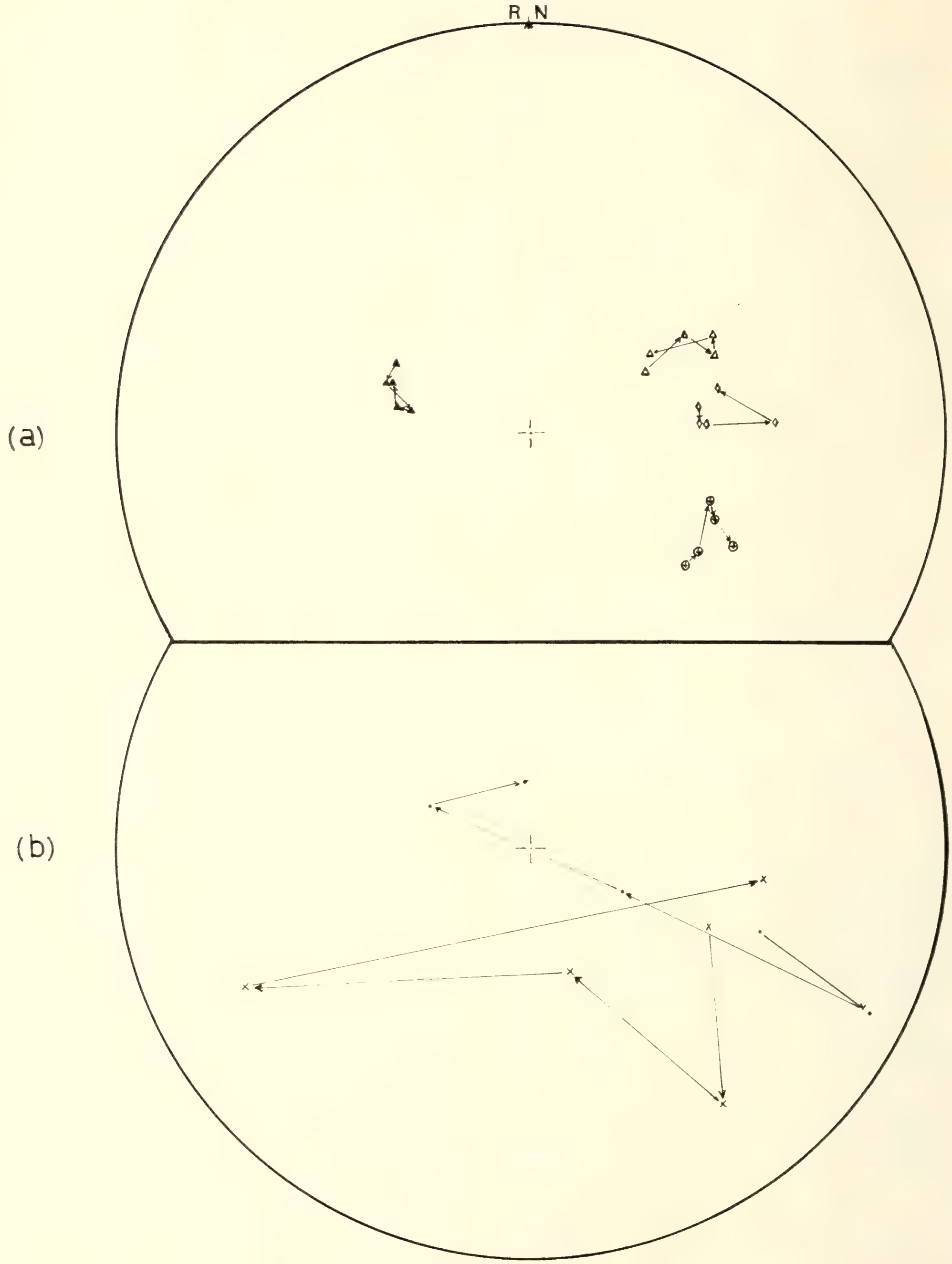

FIGURE 7—Thermal demagnetization plots up to 400° C. (stereographic equal-angle projection) relative to each specimen for the basalts from site CAN 9. The symbols are as in Figures 4 and 5, with the 100° C. steps as in Figure 5. (*a*) Group 1. (*b*) Group 2.

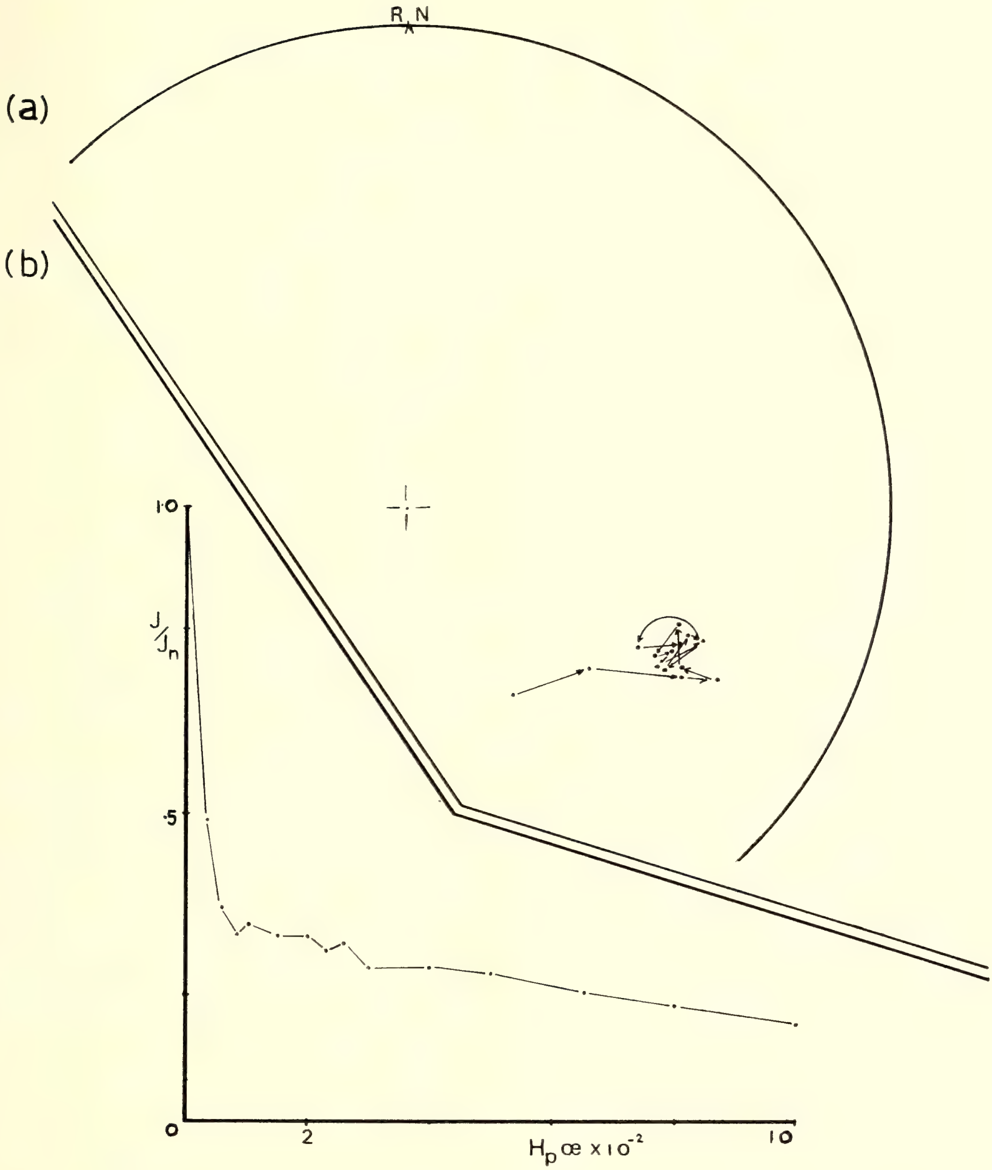

FIGURE 8—Alternating field demagnetization results for CAN 46A. Symbols and explanation as in Figures 4 and 5 except that (·) is not to be confused with CAN 9D. (*a*) Plot. (*b*) Curve. The large decrease in J_n up to 60 oersted is due to the high J_n (100×10^{-4} emu/cc).

basalts. The correlation noted by Ade-Hall and Wilson with the opaque minerals was not established here, although ilmenite was only detected as a minor accessory in Group 2.

While bearing in mind the limitations of the sampling, the overall mean magnetic vector direction after partial demagnetization for the Canobolas Mountains volcanic rocks is: declination $=132°$ T., inclination $=-44°$ (assuming all inclinations to be negative). This corresponds to a palaeomagnetic pole position of latitude 15° N., longitude 105° E., which does not agree well with previously published Tertiary poles for Australia. (This disagreement is probably due to the probable large error in the mean magnetic vector above, which has a 95% confidence circle of radius about 30°.)

Concluding Comment

The correlations between magnetic properties and petrology (etc.) that have been recorded are as yet insufficient for broad conclusions to be drawn—but they show the necessity of studying "rock magnetism" together with "palaeomagnetism". Future investigations into this problem, and increased understanding of the history of the geomagnetic field (especially the aspect of reversals) may in fact prove that the results reported here are simply coincidental, but this does not obviate the need for a petrological study as an important adjunct of palaeomagnetic investigations.

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This study was mainly conducted in 1964 during candidature for an honours degree, and I would like to thank the Head of the Department, Professor C. E. Marshall, and my supervisor, Dr. A. A. Day, and other members of the staff of the Department of Geology and Geophysics, University of Sydney. Thanks are also due to K. M. Chan, R. J. Henderson and E. P. Shelley for helpful discussions, and also Drs. R. L. Wilson, J. M. Ade-Hall and N. D. Watkins for their interest. Many citizens of Orange gave ready and valuable assistance, especially Mr. V. O'Connell. I am grateful to the District Forester at Bathurst and Mr. G. Windsor, Forester, N.S.W. State Forestry Commission, for access to the Canobolas forests, and to the management of Orange Blue Metal Pty. Ltd. for permission to sample from the quarry and supplying drill core. Finally, I would like to express appreciation to Miss E. J. Ward for typing the manuscript and to Dr. Day for critically reading the manuscript and giving helpful comments. The work on sample CAN 46A was carried out during the tenure of a Commonwealth Post-Graduate Research Studentship.

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Appendix

The locations and lithological types of the samples collected for this study are given in Tables A1 and A2, Table A1 containing the samples whose properties have been discussed above in detail.

The locations of the sampling sites are specified by their grid reference determined from the Orange Military Map (406, Zone 8, 1938 edition) or the Canobolas State Forest Map (N.S.W. Forestry Commission, 901, sh. 13, 1956 edition).

Table A1

Collection Sites of the Samples Described

Sample Number	Number of Specimens	Rock Type	Grid Reference
CAN 9A	6	(Titan)augite olivine basalt	041835
CAN 9B	3	(Titan)augite olivine basalt	041835
CAN 9C	2	(Titan)augite olivine basalt	041835
CAN 9D	6	Olivine basalt	041835
CAN 9E	2	Olivine basalt	041835
CAN 9F	6	(Titan)augite olivine basalt	041835
CAN 46A	15	(Titan)augite olivine basalt	041852

Site CAN 9 is a small quarry about 200 metres × 150 metres.

Site CAN 46 was a trench about 4 metres deep, sample CAN 46A having been collected from the bottom of the trench.

Table A2

Collection Sites of the Samples Not Described

Sample Number	Number of Specimens	Rock Type	Grid Reference
CAN 4A	3	Augite-rich rock	991880
CAN 24A	6	Olivine trachyte	930789
CAN 42A	7	Augite ? olivine trachyte	947781
CAN 3A	5	Aegirine-augite trachyte	967778
CAN 8A, 8B	6	Aegirine-augite trachyte	983771
CAN 35B	5	Augite trachyte	002734
CAN 14B	5	Augite trachyte	988728
CAN 17B	5	Augite trachyandesite (or latite)	955747
CAN 16A	4	Aegirine-augite quartz trachyte	969750
CAN 34A	5	Hypersthene andesite agglomerate	021810
CAN 31A	5	Augite olivine basalt	969699
CAN 21B	7	Augite olivine basalt	930830
CAN 40A	9	Augite olivine basalt	945826
CAN 36A	5	Augite olivine basalt	052800
CAN 37A	8	Augite olivine basalt	024826

CAN 4A is a Palaeozoic rock, and will be described elsewhere.

The remainder have been arranged in their suggested order of eruption.

The magnetic results for the samples listed in Table A2 show, after demagnetization, a slight grouping of the directions approximately towards (132°, −44°). Using this result in the method described by Manwaring (1960), the position of the South magnetic pole at the time of extrusion of the Canobolas Mountains (assuming approximate contemporaneity) was lat. 15° N., long. 105° E.

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Some Blockstreams of the Toolong Range Kosciusko State Park, New South Wales

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Abstract—Fuller investigation of the blockstreams of the Toolong Range has substantiated previous interpretation of them as part of a periglacial morphogenetic system of Upper Pleistocene age. Periglacial solifluction of blocks in a fine matrix appears to have been less important than movement with interstitial ice as matrix. This makes them akin to rock glaciers, though their meagre thickness must have prevented them moving in identical manner.

Wood of *Nothofagus* cf. *cunninghamii* in quartz gravel beneath the head of one of the blockstreams was dated by C-14 to 33,000 B.C., yet it was accompanied by a pollen spectrum at least partially Tertiary in origin through reworking of presumed sub-basaltic sediments. The wood from a tree stool *in situ* relates to warmer conditions just prior to the periglacial phase.

The basaltic regolith in the blockstreams and accompanying solifluction mantle implies a scarp retreat of about 33 m. since 33,000 B.C.

Introduction

Blockstreams have often been described as part of a typical periglacial landscape (Thornbury, 1954; Derruau, 1958), and the examples near the upper Tumut River which will be considered here have already been treated as such in a survey of periglacial features of Australia (Jennings, 1956). Similar features elsewhere in the high country of south-eastern Australia have been ascribed to the effects of late Pleistocene frost climates—in basalt and rhyodacite in the high plains of eastern Victoria by Carr and Costin (1955) and Talent (1965), in granite on the main Snowy Mountains by Galloway (1963), and in dacite, siltstone and ironstone on Cooleman Plain by Jennings (1967).

Apart from those on the Toolong Range briefly described by Jennings, there are other blockstreams around the headwaters of the Tumut River such as those on the northern end of Farm Ridge, around the head of the Rough Creek valley and above Happy Jacks Pondage on the upper slopes of Bolton Hill (Figure 1). In all these areas the blockstreams are made up of basaltic material derived from thin caps preserved only on the higher ridge crests.

The Situation of the Blockstreams

The blockstreams of the Toolong Range are found around its southern end west of the Tumut River at altitudes of 1,680–1,780 m. (5,200–5,500 feet), where they occupy the floors of shallow valleys in granite underlying a basalt cap. That cap gives the range a flat mesa-like top inclined gently eastwards. The blockstreams on the steep slopes above the river are less well defined and of more interrupted nature than those on the ground which slopes more gently to the west from the higher edge of the range top.

On the eastern slopes of the range occasional blocks of basalt litter the slopes below the blockstreams to the Tumut River itself. These are isolated, however, and are part neither of a blockfield cover nor of a solifluction mantle. On the western slopes, one or two blockstreams extend down the whole slope to the edge of the mires in the valley bottoms (Plate 7). On this side are found the best developed of these forms and work has been concentrated on them (Figure 2).

The Form of the Blockstreams

Fezer (1953) has suggested that the term " blockstream " be restricted to those features of blockfield nature which are substantially more extensive in downslope direction than across the slope. Caine (1966) has defined the essential features of a blockfield as " a sheet-like cover of contiguous blocks, a low angle of slope (15° has been suggested as the upper limit), a lack of interstitial fine material in the surface layers, and a lack of vegetation, apart from lichens and mosses ".

The blockstreams of the Upper Tumut area come within these definitions. They have

downslope dimensions five to ten times their average width and many floor shallow valleys, which are partly responsible for their form. The main ones on the western slopes of the Toolong Range, with which this paper is primarily concerned, range from 150 to over 300 m. in length, and reach a maximum individual width of 70 m., though two adjacent streams merge along part of their lengths to give a combined width of 85 m.

Slope angles on the western blockstreams of the Toolong Range are generally about 9°, ranging between 4½° and 12° along the main bodies of the three examples surveyed (Fig. 3, Plate 3). On the blockstreams of the eastern side of the Toolong Range, however, markedly steeper block-covered slopes can be found. Here angles in excess of 15° are not uncommon, and may occasionally be more than 25°. Nevertheless their overall slopes are significantly less

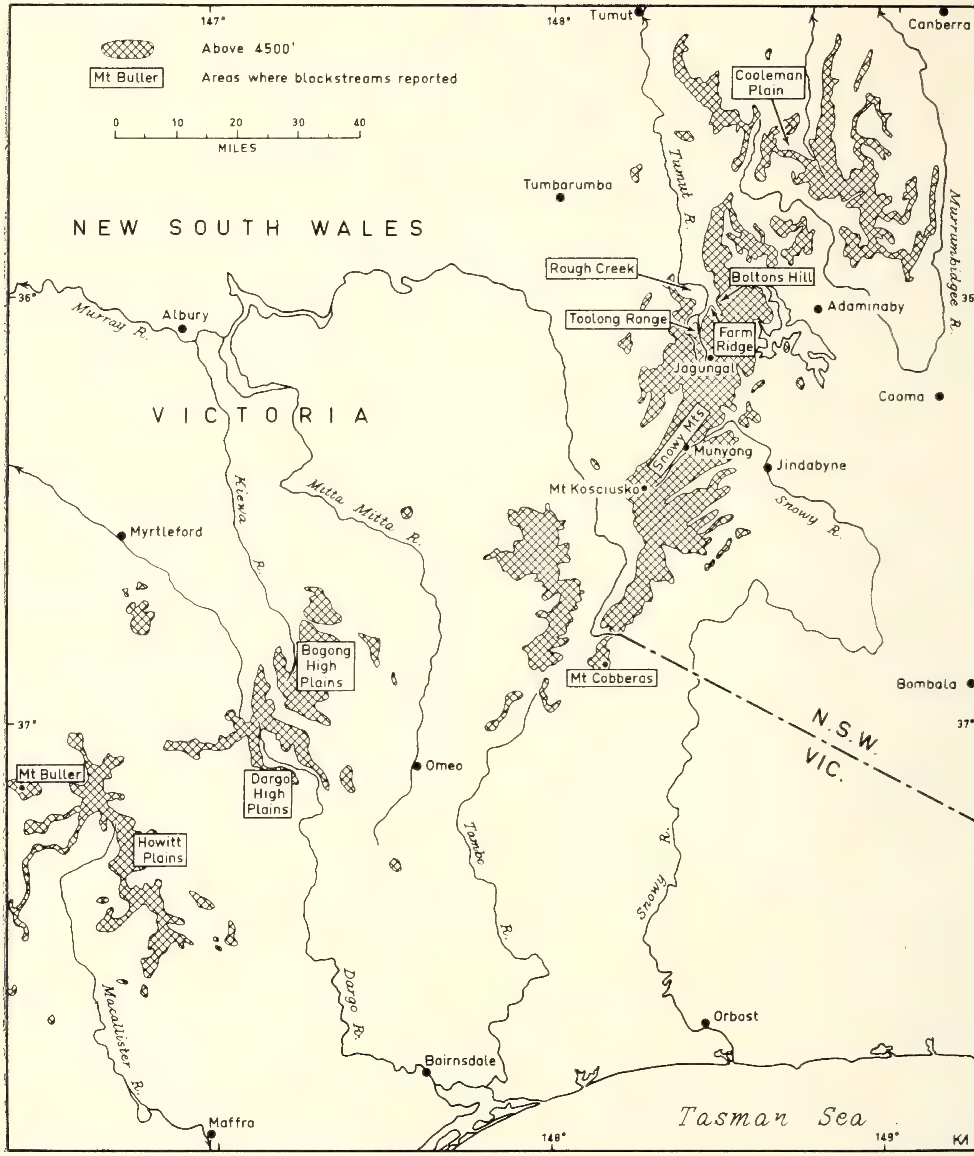

FIGURE 1—Location of blockstreams reported from the south-eastern Australian mainland.

steep than talus slopes such as, for example, those on the lower flanks of Happy Jacks River valley upstream of the Pondage.

The Farm Ridge blockstreams are similar to those on the eastern side of the Toolong Range, though more extensive. Lower angle blockstreams more akin to those of the western side of the Toolong Range are found on the eastern flank of the Rough Creek valley.

blockstream 6. Instead, there is a steep slope of loosened basalt columns which have been subject to downslope rotational movement over a basal hinge. Every stage of tilting and detachment from the original vertical posture in the bedrock scarp to complete displacement and downslope inclination in the blockstream can be seen (Plate 2). These steep slopes have angles of 25–30° and heights of 3–10 m.,

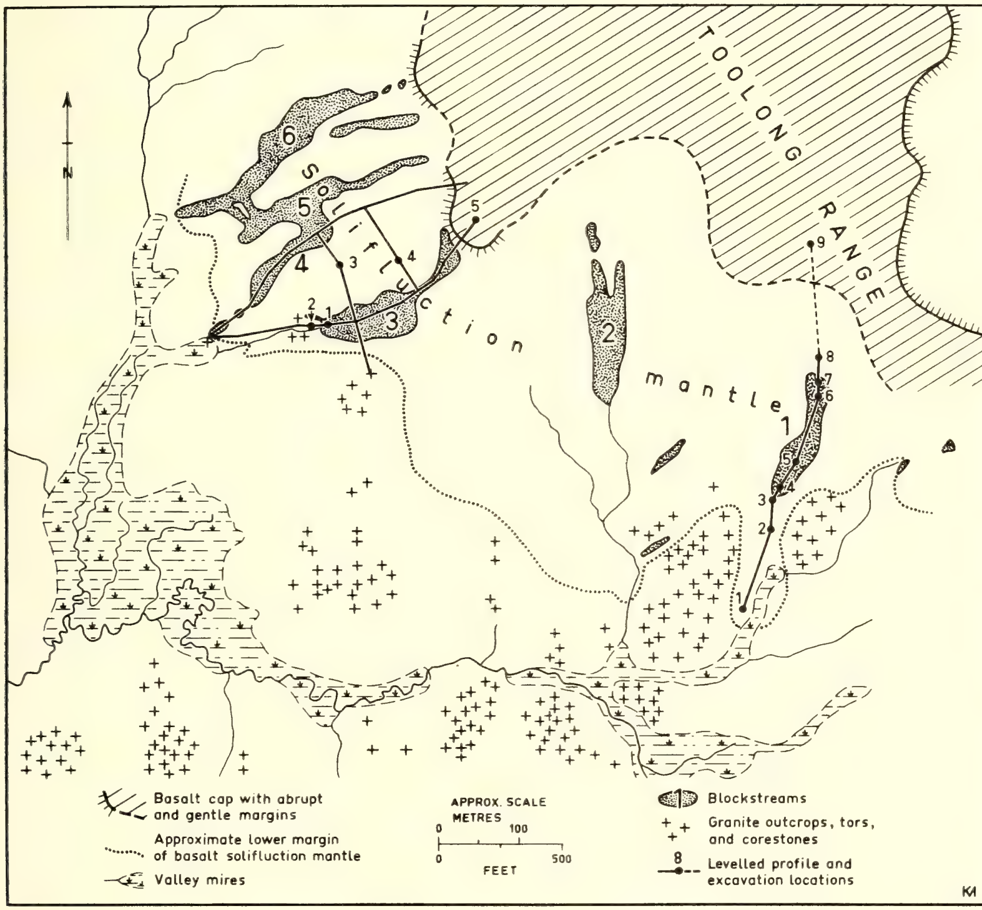

FIGURE 2—Western slopes of the southern end of the Toolong Range, New South Wales.

On the Toolong Range the bare block cover may begin as much as 100 m. from the edge of the basalt-capped plateau, with no marked break in the slope profile at their beginning, e.g. blockstreams 1 and 4 (Figure 3). Some of the blockstreams, however, reach to the very edge of the plateau, e.g. blockstreams 3 (Figure 3), 5 and 6, much attenuated in width in their higher parts. At the edge there is virtually no free face, though about a metre of columnar basalt in place is seen at the head of rendering the top parts of the long profiles concave.

The main bodies of the blockstreams have a generally rectilinear long profile, a somewhat concave cross profile, and edges slightly higher than the neighbouring ground. Occasionally the long profiles are varied by inclined steps or berms running across their width. Hollows about 1 m. deep pit their surfaces in parts (Plate 6) but exhibit no regularity in their distribution. The blocks exposed in these

pits remain free of interstitial fine material and are bare but for lichens and mosses.

The upper part of blockstream 2 has some longitudinal V-shaped grooves up to 2 m. deep separating rounded ridges. In this respect it resembles the blockstreams on the steeper slopes on the Tumut River side of the range and on Farm Ridge, which are occasionally grooved and ridged up and down slope in this manner.

At their lower ends some of the western blockstreams are gently convex in cross-section and have relatively steep bulging toes which may be more than 2 m. higher than the ground below (Fig. 3, Plate 8) and have a 20–30° slope. Above the best developed toes there is a level or even slightly hollowed area in which pitting is more common than generally on the blockstreams.

The Structure of the Blockstreams

The material making up the blockstreams themselves is almost entirely basalt derived from the plateau cap. In most of them there is a progressive change from a predominance of hexagonal parallelopipeds, 0·5–2 m. long, at their heads (Plate 3) to more compact, less regular and more rounded blocks near the toes (Plate 5). With this trend there is also a reduction in average size. However, short columns with primary contraction joint faces surviving may still be found occasionally near the toes. The change in shape and size may also take place rapidly as in the case of blockstream 6, where it occurs over an interval of a few metres about halfway down its length. No attempt has been made to define block shape quantitively, so no statistical assessment of this contrast can be made. Some joint faces show linear corrosional etching up to 2 cm. deep perpendicular to the principal axes of the parallelopipeds.

At the lower ends of the blockstreams occasional blocks of granite may be seen amongst the basaltic material; they are usually larger and more spheroidal than the latter.

Although attempts have been made in other blockstreams, efforts to determine the structure in depth by excavating and augering have only been successful in the instance of blockstream 1, where blocks were generally smaller. The structure of blockstream 1 conforms broadly to a pattern which has been found repeatedly in the much larger dolerite blockfields of Tasmania (Caine, 1966), so it can be assumed to be typical for the Toolong area also. This structure is one of three principal layers (Figure 4A):

(i) An upper layer consisting of matrix-free blocks. Between the blocks are occasional gatherings of angular gravel which has weathered from them. Towards the bottom, block size tends to be rather less than higher up. In blockstream 1 this upper layer is 1 to 1·5 m. thick (Plate 4).

(ii) Below is a block layer in which the interstices are filled by black humic material (Plate 4). The upper surface of this layer is usually littered by gravel weathered from blocks above and it is normally the watertable also. This layer is 20–40 cm. thick in blockstream 1 but a greater thickness of at least 60 cm. was met in one hole near the toe of blockstream 3.

(iii) Below this again is the lowest layer of block material with the spaces between the blocks filled by a dark brown silty sand. The thickness in blockstream 1 was up to 50 cm.

In the holes through blockstream 1 these layers with basalt blocks have been found to overlie a residual granite grus which retains the original structure of the granite. Quartz and mica are largely unaltered, but the felspars are almost entirely decomposed, pseudomorphic clay replacing them. In some holes part of the granite profile has weathered to a high clay content. The auger hole of Section 7 contained so much water that the precise level of the grus surface could not be ascertained. Above it is a brown slightly humic quartz gravel layer at 180–256 cm. which contained much carbonized wood, with humus-free quartz gravel above and below.

No evidence of downslope movement of this granite waste mantle was encountered except immediately below its contact with the blockstream material, where a thin mixed layer was found with small pieces of basalt amongst the granite minerals. Correspondingly, the lower parts of the lowest blockstream layer show a gradually increasing enrichment in quartz grains as the contact with the rotten granite was approached.

The Structure of the Neighbouring Ground

A few holes were also put down outside the bare blockstreams to give some idea of the context in which they lie.

At two points on the basalt plateau basalt *in situ* is encountered between 10 and 75 cm. down. In the larger excavation (section 5 of

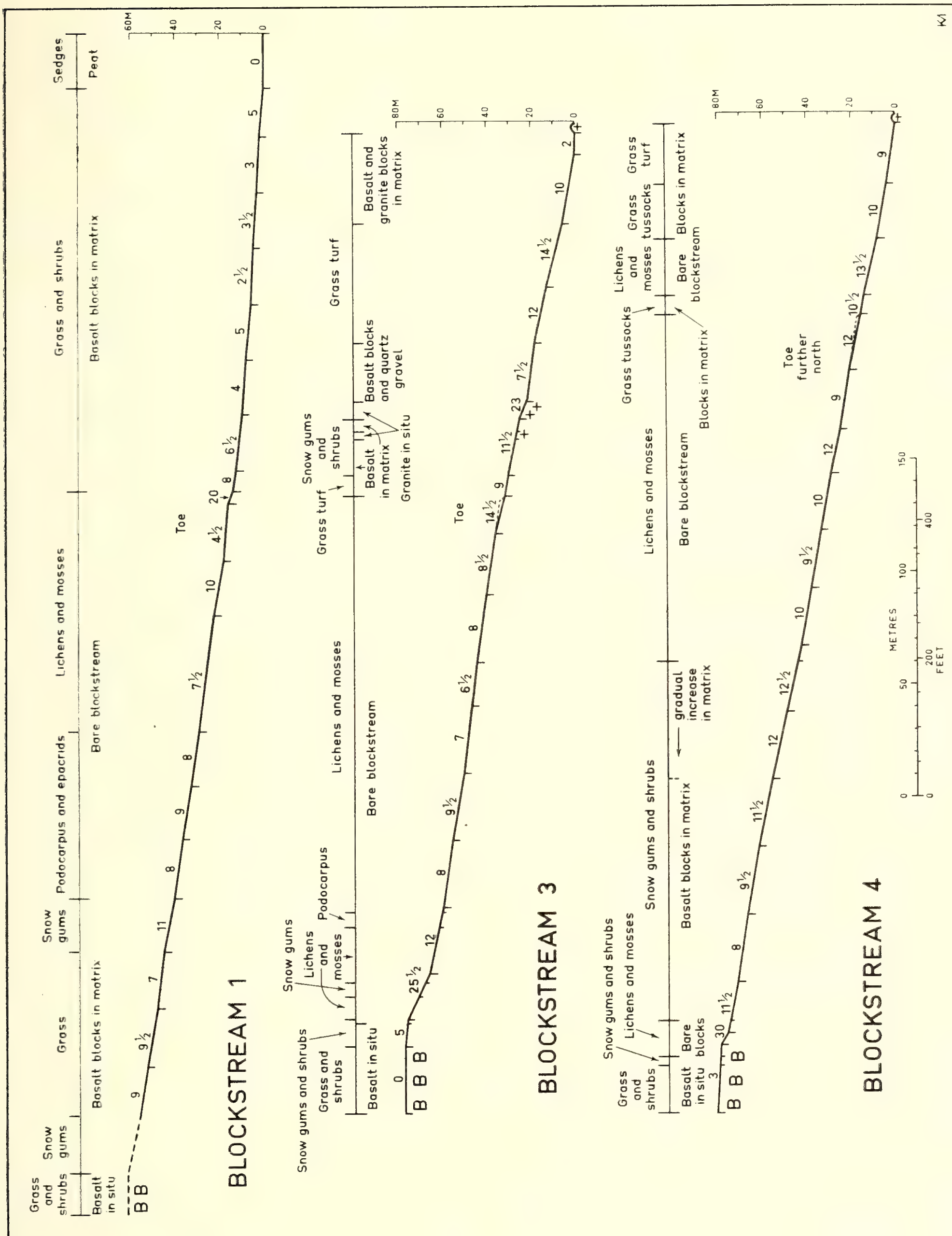

FIGURE 3—Longitudinal profiles of three blockstreams of the Toolong Range.

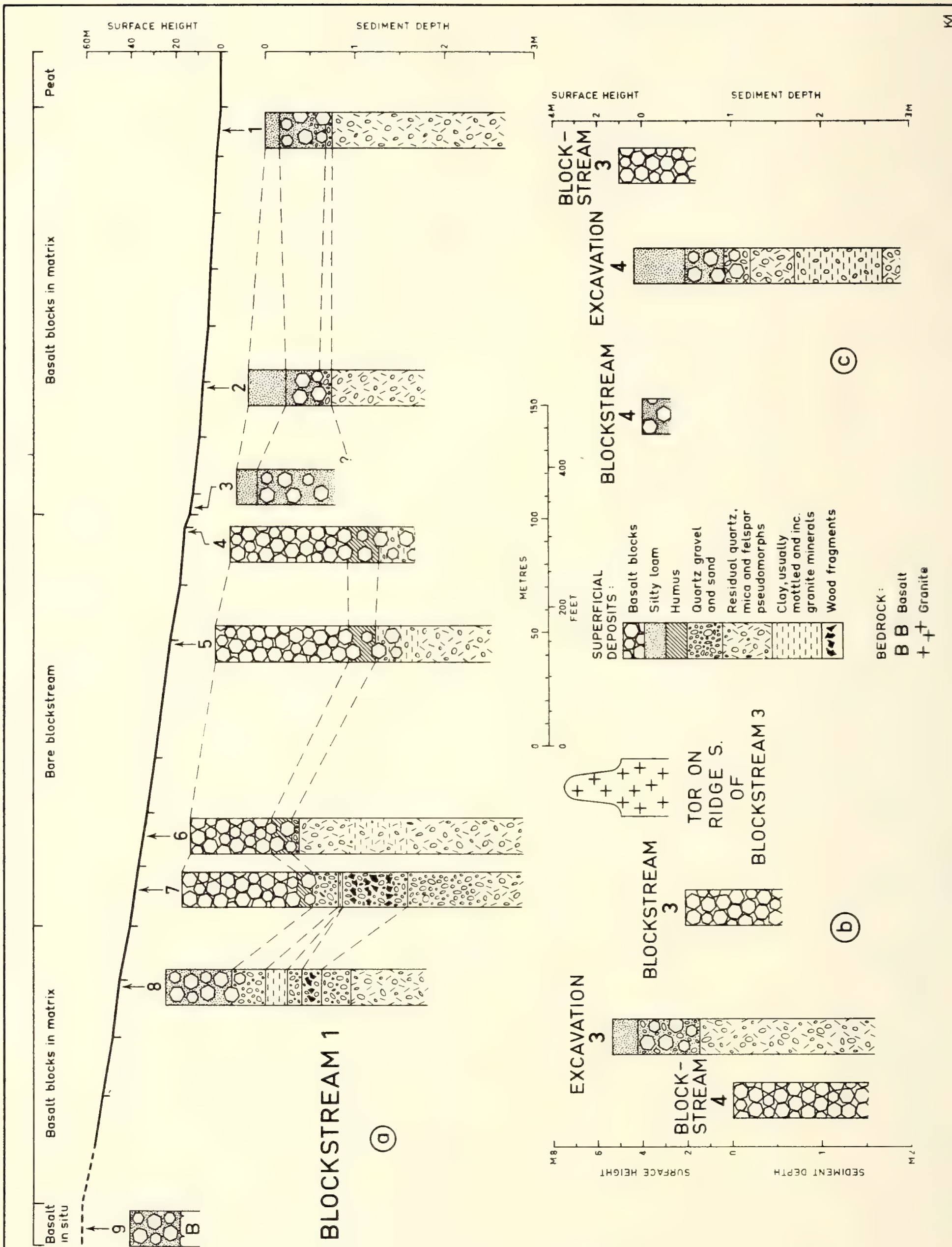

FIGURE 4—Structure of blockstream 1 and of the divide between blockstreams 3 and 4. See Figure 2 for location of the excavations.

blockstream 3) the basalt columns are tightly locked together at a depth of 60 cm. or less with no weathered material between them, although parts of their tops are covered with a biscuit-coloured weathered rind (Plate 1).

Situated between the basalt cap and the top of blockstream 1, section 8 has a surface layer of basalt blocks in a matrix grading from very dark brown crumbly loam above to yellow brown silt loam below. This 80 cm. layer sharply overlies granitic materials, consisting chiefly of quartz gravel which has been transported in some degree. The topmost 63 cm. is organized into a soil profile with an organic-rich clay horizon ; below this at 157 to 178 cm. depth a silty layered horizon contains woody fragments. Below 213 cm. the material has the characteristics of residual weathered granite.

Section 8 belongs to an apron of rather uniform slope below the steep margin of the basalt cap, with no valley development in it and with no exposures of granite. Where bare blockstreams reach through it to the basalt cap above, they are notably narrower than further down but are at the level of the intervening ground (Figure 4*c*). This vegetated intervening ground commonly has basalt blocks projecting through the soil or else a very dark brown crumbly loam forms a surface layer. In section 4, between blockstreams 3 and 4, this completely stone-free layer is 60 cm. thick, and below is a layer with basalt blocks in a matrix similar to that already described for section 8. Underlying this is a thin layer of granitic material including small pieces of basalt above residual granite grus and mottled red clay. The top of this residual granitic material lies 25 m. below the top of the range, but it is thought that the basalt cap is considerably less than this in thickness.

Below this zone the slopes carry valleys. These are well developed on the south-facing part of the western slopes with the bare blockstreams sitting well down in them. The west-facing part is very much flatter and surveying and excavations were necessary to prove that the bare blockstreams occupy the lowest parts of these slopes (Figure 4*b*). The ridges and low swells between the blockstreams are largely covered with basalt blocks in a loam matrix, though granite gravel and granite outcrops appear over their lower parts. Bedrock granite is exposed most extensively, and to its greatest altitude, below the projecting south-west corner of the basalt cap ; less basalt would have been shed on to this ridge from the retreating edges of the cap. Granite is exposed here only 30 m. below the crest of the range. Section 3, between blockstreams 3 and 4, has a similar sequence to that of section 4, though the block-free surface layer is rather thinner and the residual granitic material includes no heavy clay layers.

Sections 1, 2 and 3, below the toe of blockstream 1, all have a surface layer of basalt blocks in a dark loamy matrix, overlying residual weathered granite (Plate 8). The surface layer belongs to a flat-topped tongue of valley fill below granite slopes on either side. Similar tongues project down valleys below some of the other blockstreams.

The Origin of the Blockstreams

The general character of the blockstreams, but especially their elongation downslope at a very low angle for such materials and the frequently sharply unconformable contact of the basaltic material with the decomposed granite place these features amongst the products of mass movements associated with periglacial conditions rather than amongst convergent forms found in tropical monsoonal areas such as Hong Kong (Wilhelmy, 1958).

Two processes of mass movement associated with frost climate are relevant : a solifluction or congelifluction movement at a time when the interstices between the blocks, at present void, were filled by a fine matrix material such as is now present in the lowest layer only of the blockstreams, and a flow movement when these interstices were filled by ice, perhaps resulting from Balch ventilation between the blocks (Thompson, 1962).

The first process of solifluction with a matrix seems undoubtedly to have taken place in some degree since the lowest layer of the blockstreams and the top of the underlying granitic material show a mixing of fragments of basalt with finer particles of granitic origin. This process may also account for the layers of basalt blocks with loam matrix on the ridges and slopes between the blockstreams and also in the valleys below their toes. These layers resemble very much periglacial solifluction mantles described from Tasmania (Nichols and Dimmock, 1965). Nevertheless, the stone-free loams overlying some parts of these layers are difficult to explain except by their subsequent emplacement either by surface wash or less probably by aeolian action. The possibility that at least some of the loam matrix in the block layers may be of similar origin cannot be excluded.

On the other hand, narrow lanes and small patches of matrix-free blocks within areas where block layers with loam matrix are found at

the surface seem to be due to the washing out of fines subsequent to the emplacement of a solifluction mantle.

That emplacement of blockstreams without sediment matrix, and so implicitly with interstitial ice as the lubricant, was important, seems to be borne out by various pieces of evidence from the Toolong Range blockstreams. Substantial proportions of certain blockstreams consist almost entirely of basalt columns; these columns can be seen at the heads of certain streams to have been fed into them devoid of matrix from the bedrock and the summit excavation demonstrates the absence of weathered material between the columns still *in situ*. It seems that frost wedging has produced matrix-free block material in this way. The irregular pattern of pits on the surface of the blockstreams can also be explained by the melting of large bodies of the interstitial ice which permitted downhill movement at modest angles; if these pits had been due to fluvial removal of material from beneath the blockstreams, they would tend to occur in lines downslope. The bulging form of the toe and the flat or slightly hollowed area immediately above it on some of the blockstreams also favour this kind of origin. It seems unlikely that suffosion by wash processes would succeed in removing the fine material from the entire toe and leave such a bulging form. Sections 3 and 4 in the blockstream 1 profile, respectively immediately below and just above the toe, suggest an unconformable contact between the blockstream and the tongue of solifluction blocky earth below it. This lends further support to the hypothesis of movement of blocks with interstitial ice between them as responsible for some of the blockstreams (cf. Talent (1965) on Victorian blockstreams).

Nevertheless the mechanism of deformation cannot be the same as that inferred by Wahrhaftig and Cox (1959) for Alaskan rock glaciers in which interstitial ice is regarded as essential. Employing a viscous flow model, they find strong similarity between the movement of the rock glaciers and that of true glaciers. The Toolong blockstreams are in fact too thin for shear stress at their base to reach the critical minimum value of about one bar for such movement (Wahrhaftig and Cox, 1959).

Movement of the blockstreams is not continuing at the present time. This is proved by the presence of lichens on the upper surfaces only of the blocks, by the occurrence of freshly frost-shattered blocks which exhibit no sign of movement, and by the lack of mixing of the lower two layers of blockstream 1. Moreover, plants are actively colonizing the margins and narrow parts of bare blockstreams (Plate 6) and organic debris is filling up the voids between the blocks. At many points a gradual lateral change from bare blocks with empty interstices to blocks completely enveloped in this way can be seen. *Podocarpus lawrencei* Hook f., *Eucalyptus niphophila* Maiden and Blakely, and *Drimys lanceolata* Baill. are the chief plants involved in this process of colonization and show no sign of the damage activity of the blockstream would cause. The vegetation around the blockstreams is, of course, responsible for the humic matrix of the second layer in vertical structure. The instability of occasional blocks, and their settling and rolling, do not deny the interpretation of the essential movement and emplacement of the blockstreams in terms of frost action in a more severe climatic phase than at present.

However, not all the material present in the blockstreams need have been produced by periglacial weathering. It may be that the regularly shaped blocks of the upper parts of the streams are the result of frost wedging of the well-jointed basalt, whilst the more rounded smaller blocks lower down have been derived from earlier and different weathering processes. This has been suggested previously for material involved in the blockfields of Tasmania (Caine, 1966). The sudden change in shape and size of the blocks in at least one of the streams of the Toolong Range supports this double origin of the blocks themselves.

Chronology and Climatic Change

The wood from the quartz gravel in section 7 beneath blockstream 1 has been dated by radiocarbon at $35{,}200^{+1{,}600}_{-2{,}150}$ years B.P. (A.N.U. 76) and this provides a maximum age for the deposits above it. The interval between this date and the emplacement of the blockstream may not have been very long since the protective effect of the overlying material would be needed to maintain sand and gravel on this slope of 8°. A. B. Costin has investigated an analogous situation at Munyang in the Snowy Mountains not far to the south in which a humic soil is buried by solifluction fill of periglacial origin and has provided a date of 32,000 years B.P. It is likely that these periglacial mass movements, the most substantial of their kind in both areas, occurred during the cold phase responsible for cirque and valley glaciation

in the highest parts of the Snowy Mountains. Costin has dates which suggest that this glaciation occurred prior to 15–20,000 years B.P. It would seem, therefore, that the blockstreams can be allocated to a cold phase broadly equivalent to the final and maximum phase of the Weichsel-Wisconsin Glacial Period.

The occurrence of the blockstreams, some of the evidence from which implies interstitial ice for their movement, indicates a mean annual temperature below 0° C. when they were active. The present mean annual temperature in the vicinity of the blockstreams is estimated from the lapse rate derived from the nearest climatological stations at 5–5·5° C. (41–42° F.). A lowering of 6° C. at least for the late Pleistocene may be compared with the 9° C. argued by Galloway (1965) for the area on other grounds. Since thick and long persistent snow cover would be inimical to their development, there may be as well a suggestion of lowered absolute precipitation, which has also been inferred for south-eastern Australia by Galloway.

The wood of section 7 was originally obtained by auger, but subsequently a small excavation was made to get a larger sample. The shape and disposition of the wood were such that Dr. P. W. Williams and the one of us present (J.N.J.) accepted it without question during extraction as the remnant of a tree stool *in situ*. Unfortunately in view of subsequent findings no attempt was made to measure and draw up a section which would have demonstrated this.

The wood has been identified by Dr. H. D. Ingle (pers. comm.) from a number of pieces as " in all probability *Nothofagus* of the southern group cf. *N. cunninghamii* ". The humic gravel around the top of the stool was analysed for pollen and spores, and Dr. D. Walker's report is included below. We concur with his interpretation that the spectrum most probably indicates at least a substantial proportion of *remanié* Tertiary pollen. Lacustrine and fluvial sediments beneath Tertiary lava are common in the area ; although no section or boring has demonstrated a similar occurrence beneath the Toolong Range lava capping, inference to this effect can be made with some confidence. The detrital gravel beneath the blockstream must have derived its content of Tertiary pollen from such a source.

Thus the *Nothofagus* wood is the only reliable floristic indicator of conditions shortly preceding the emplacement of the blockstream. At least it proves that about 33,000 B.C. there was a period warmer than the succeeding cold period in which the main periglacial, and probably the glacial, phenomena of the high mountains of southern New South Wales developed.

Scarp Retreat

An approximate calculation of the retreat of the basalt cap necessary to provide the material in the solifluction mantle and the blockstreams can be made. The thickness of the basalt cap may be put at 10 m., i.e. slightly more than the greatest height of the steep marginal slope ; if at fault, this will be an underestimate. The average thickness of slope material above the granitic layer in the eight holes excavated down to it is 1·15 m. ; this is probably an overestimate when used as a measure for the whole slope, since the blockstreams are thicker and over-represented in the sample. Reducing this 1·15 m. to 1 m. to allow for porosity is also erring on the generous side for the volume of displaced basaltic material. With an area of 341,000 m.^{2} from a basalt front of 1,040 m., the mobilized basalt regolith represents a retreat of the basalt margin of 33 m. This retreat, almost certainly maximized in the estimation, lies within the width of the uniformly sloping apron below the steep marginal slope of the basalt residual.

As has been mentioned in discussion above, it cannot be assumed that all the basaltic waste is the product of periglacial weathering, though it is largely of this origin. But since it has reached its present disposition by periglacial processes, and since the dated section 7 lies quite close to the residual basalt, it appears that virtually all this retreat has taken place since 35,000 B.P.

Acknowledgements

We are particularly grateful to Dr. H. D. Ingle of C.S.I.R.O. Forest Products Division for the wood identification ; to Dr. J. Lovering and Mr. H. Polach for the C-14 data from the A.N.U. Radiocarbon Laboratory ; to Dr. Walker and Mrs. J. A. Williams for the pollen analysis. Dr. A. Costin generously allowed us to refer to unpublished data and commented on the manuscript. Dr. P. W. Williams and Mr. A. Hodgkin gave valuable help in the field.

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Appendix 1

POLLEN ANALYSIS OF A SOIL FROM TOOLONG, N.S.W.

D. WALKER

Australian National University, Canberra

The material was prepared for examination by a standard acetolysis method. A total of 533 pollen grains and 50 spores was examined, 500 of the former being allocated to living taxa and all of the latter being placed in morphological groups. The pollen grains and spores were in uniformly good condition after preparation.

Of the taxa identified, *Nothofagus* subsect Bipartitae, *Dacrydium*, *Microcachrys*, *Phyllocladus* and cf. Pinaceae do not grow on the Australian continent today. Excluding cf. Pinaceae, which is a common contaminant of preparations made in Canberra, this group, together with *Nothofagus* cf. *cunninghamii*, *Casuarina* and *Podocarpus*, forms an assemblage commonly recorded from Tertiary deposits. Indeed, after allowing for differences in the nomenclatural systems used, all these identifications can be matched with determinations from the supposed Early Tertiary (and certainly "pre-basalt") strata at New Chum Hill and other sites near Kiandra, about 40 km. distant from Toolong. *Quintinia*, *Eucryphia* and *Hypericum* are genera represented in the modern Australian flora but also in highland forests of New Guinea, a region which they share with *Nothofagus* subsect. Bipartitae spp., *Phyllocladus* sp., *Podocarpus* spp., and, less characteristically, *Dacrydium* sp., and *Casuarina* sp.

TABLE 1

Pollen and Spore Analysis of a Soil Sample from Toolong, N.S.W.

	Number Counted
Pollen grains :	
Casuarinaceae :	
Casuarina	1
Cyperaceae	48
Eucryphiaceae :	
Eucryphia	1
Fagaceae :	
Nothofagus subsect. Bipartitae	158
Nothofagus cf. *cunninghamii*	15
Nothofagus	7
Gramineae	1
Hypericaceae :	
cf. *Hypericum*	20
Myrtaceae	17
cf. Pinaceae	4
Podocarpaceae :	
Dacrydium	8
Microcachrys	2
Phyllocladus	4
Podocarpus	98
cf. Resedaceae	10
Saxifragaceae :	
Quintinia	93
cf. Umbelliferae	13
Indet.	33
	—533
Spores :	
Monolete :	
Psilate	2
Verrucate	4
Trilete :	
Psilate	14
Gemmate	16
Verrucate-echinate	14
	— 50
	583

Preparation and determinations by J. A. Williams.

PLATE 1

Excavation on basalt cap, showing tops of close-fitting columns beneath a shallow soil.

PLATE 2

Steep slope at head of blockstream 6, showing rotation of columns from the edge of the cap.

PLATE 3

View down blockstream 3, showing parallelopipeds characteristic of upper parts of the blockstreams.

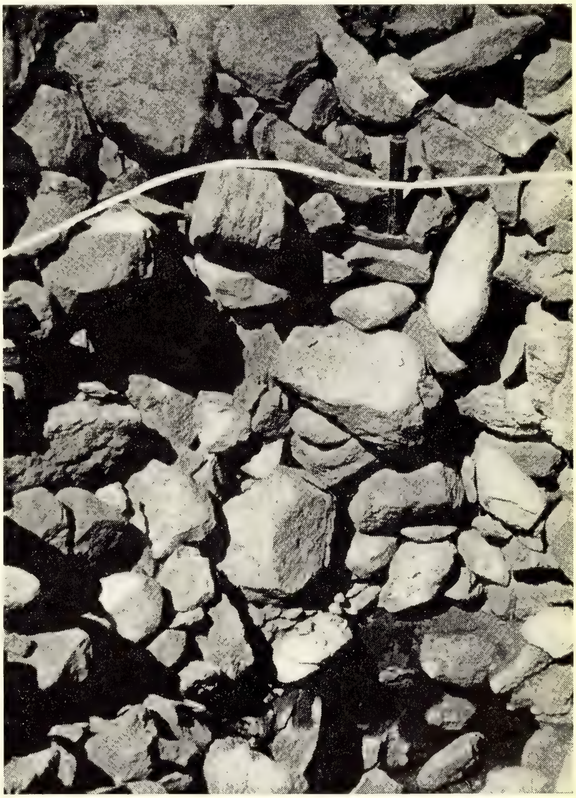

PLATE 4

Excavation 4 in blockstream 1. The white line indicates the surface of the blockstream and below 130 cm. of matrix-free blocks black muck in the interstices can be seen.

Plate 6

Plate 8

Plate 5

Plate 7

There is therefore nothing in the Toolong flora to distinguish it from certain Tertiary assemblages of south-eastern Australia, except the stump of *Nothofagus* cf. *cunninghamii* dated to $35{,}200^{+1600}_{-2180}$ B.P.

The data permit of four tentative interpretations. First, it might be argued that a rainforest vegetation somewhat similar to that found in parts of the New Guinea highlands, but with at least one genus (*Microcachrys*) now monospecific and endemic to Tasmania, persisted in parts of New South Wales from the Early Tertiary until 35,000 years ago. Secondly, on the basis of the certain dating of the tree stump, the chronology of all other sites which have revealed floras of this type might be called into question. Thirdly, the radiocarbon date might simply be wrong. Finally, the dated *Nothofagus* stump and at least part of the pollen contained in the soil may not be contemporaneous. Although there is nothing in the field evidence to substantiate it, this last explanation is less taxing of the imagination than the others. It is not difficult to envisage *Nothofagus cunninghamii*, currently native in Victoria, growing at Toolong 35,000 years ago, nor yet *Eucryphia*, *Hypericum*, Myrtaceae, *Casuarina* or *Podocarpus* (perhaps even *P. lawrencei* which grows there today). But to do the same for *Nothofagus* subsect. Bipartitae, *Dacrydium*, *Phyllocladus* and *Microcachrys* offends against the consensus of data about their general Cenozoic migrational history. The least objectionable conclusion, therefore, is that a tree of *Nothofagus cunninghamii* grew in Late Pleistocene time on a soil which was at least in part detrital from a Tertiary deposit and that the pollen content of that soil cannot be used as a reliable guide to the vegetation of any specific period at Toolong since the Early Tertiary.

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Explanation of Plates

Plate 5—Smaller, less regular and more rounded blocks near the bottom of blockstream 4. The lighter coloured boulder just in front of the man is of granite.

Plate 6—Natural pit in blockstream 4. The bare blockstream is here being colonized by *Podocarpus laurencei*.

Plate 7—Blockstream 6 and a small part of blockstream 5 visible amongst snow gums. Blockstream 6 reaches from the basalt cap forming the skyline almost to the valley bottom, and occupies a shallow valley in the hillside.

Plate 8—Toe of blockstream 1. The man is standing on blocky solifluction earth covering the valley bottom below the blockstream.

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Mesozoic Geology of the Gunnedah-Narrabri District

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Abstract—Garrawilla Lavas extend north from the Mullaley centre of extrusion, through Willala and Delwood to the vicinity of Boggabri. They gradually become less continuous until erosional residuals, originally submerged beneath Purlawaugh deposits, occur as isolated outcrops surrounded by Mesozoic sediments. No Garrawilla volcanics have been established in outcrop areas between Boggabri and Narrabri, or at depth either beneath or west of Bohena Creek. The threefold subdivision of Mesozoic sediments into basal Triassic Digby and Napperby Beds (equivalent to the Narrabeen Group), Jurassic Purlawaugh Beds, and overlying Pilliga Sandstone, persists north from the Mullaley area to Narrabri, without significant changes in lithology.

Introduction

Earlier surveys (Kenny, 1963 ; Dulhunty, 1965) in the Coonabarabran-Gunnedah region, to the south and south-west of the Gunnedah-Narrabri district, revealed a stratigraphical sequence passing up from Permian coal measures, through Digby and Napperby Beds of Triassic age (Dulhunty and McDougall, 1966) to Garrawilla Lavas, followed by fossiliferous Jurassic Purlawaugh Beds and Pilliga Sandstone.

Recent investigations (Dulhunty, 1966) in the Mullaley-Tambar Springs-Rocky Glen district have shown that trachyte and trachy-basalt flows, extruded from vents now occupied by intrusive alkaline rocks, are interbedded and continuous with Garrawilla Lavas and form part of the Garrawilla Volcanism of late Triassic or early Jurassic age.

The main eruptive centre of Garrawilla Volcanism was situated in the Mullaley-Tambar Springs-Rocky Glen district where acid and basic alkaline lavas, interbedded with pyroclasts, piled up on Triassic sediments to thicknesses probably in excess of 2,000 feet where Mt. Bulga now stands. The more basic lavas flowed out in all directions and, supplemented by outlying subsidiary eruptions, covered wide areas. During and following the volcanism, regional subsidence continued and freshwater Triassic lakes persisted into Jurassic time. Purlawaugh sediments were deposited in the early Jurassic lakes with shorelines around islands of Garrawilla Volcanics. Although the islands were rapidly reduced in height by erosion, they remained above lake waters until later in Jurassic time, when Pilliga sands were deposited, over lapping Purlawaugh sediments along island shorelines. Whether or not the eroded surfaces of the highest Garrawilla islands were covered by Pilliga lake waters before late Jurassic subsidence ceased, is as yet uncertain. However, the present-day dome of Mt. Bulga, flanked by trachyte flows, still rises above the early Tertiary plateau surface of the surrounding Pilliga Sandstone.

The purposes of the present investigations were (i) to discover the extent of Garrawilla extrusion north from the main eruptive centre near Mullaley, (ii) to study continuity of lithofacies and Mesozoic stratigraphy north from the Coonabarabran-Gunnedah region, along the south-eastern margin of the Great Artesian Basin, and (iii) to gain further knowledge of the palaeogeography of Garrawilla Volcanism and Mesozoic sedimentation.

No previous investigations had been carried out in the Mesozoic outcrop area, lying between the Namoi River and the eastern side of the Pilliga Scrub, in the Gunnedah-Narrabri district. Relief is very low, outcrops are very poor, and field interpretation depends largely upon relation of soil types and vegetation characteristics to underlying rocks, although sufficient outcrops of rock *in situ* were found to establish adequate controls.

Mesozoic Stratigraphy

The area investigated, and an interpretative geological map, are shown in Fig. 1. Although detailed investigations were confined to Mesozoic rocks, outcrops of Permian sediments and volcanics are shown along the eastern side of the map, where they have been described by Hanlon (1948) and Voisey (1964). Conglom-

erates immediately overlying fossiliferous Permian sediments are regarded as Triassic and equivalent to the Digby Beds as originally described by Kenny (1963). Overlying shales and flaggy calcareous sandstones, also described by Kenny (loc. cit.) and termed Napperby Beds, are included with Digby Beds as Triassic in Fig. 1.

The Triassic age of the Digby and Napperby Beds is inferred from the occurrence of chocolate shales, of Narrabeen Group type, near Gunnedah (Kenny, 1963) and a potassium-argon date of 193 million years obtained for a Garrawilla lava flow overlying Napperby Beds near Mullaley (Dulhunty and McDougall, 1966).

On passing north from the Gunnedah-Mullaley area, through the Gunnedah-Narrabri district, the general lithological characteristics of Digby and Napperby sediments persist, but thicknesses vary, possibly in relation to distance from the

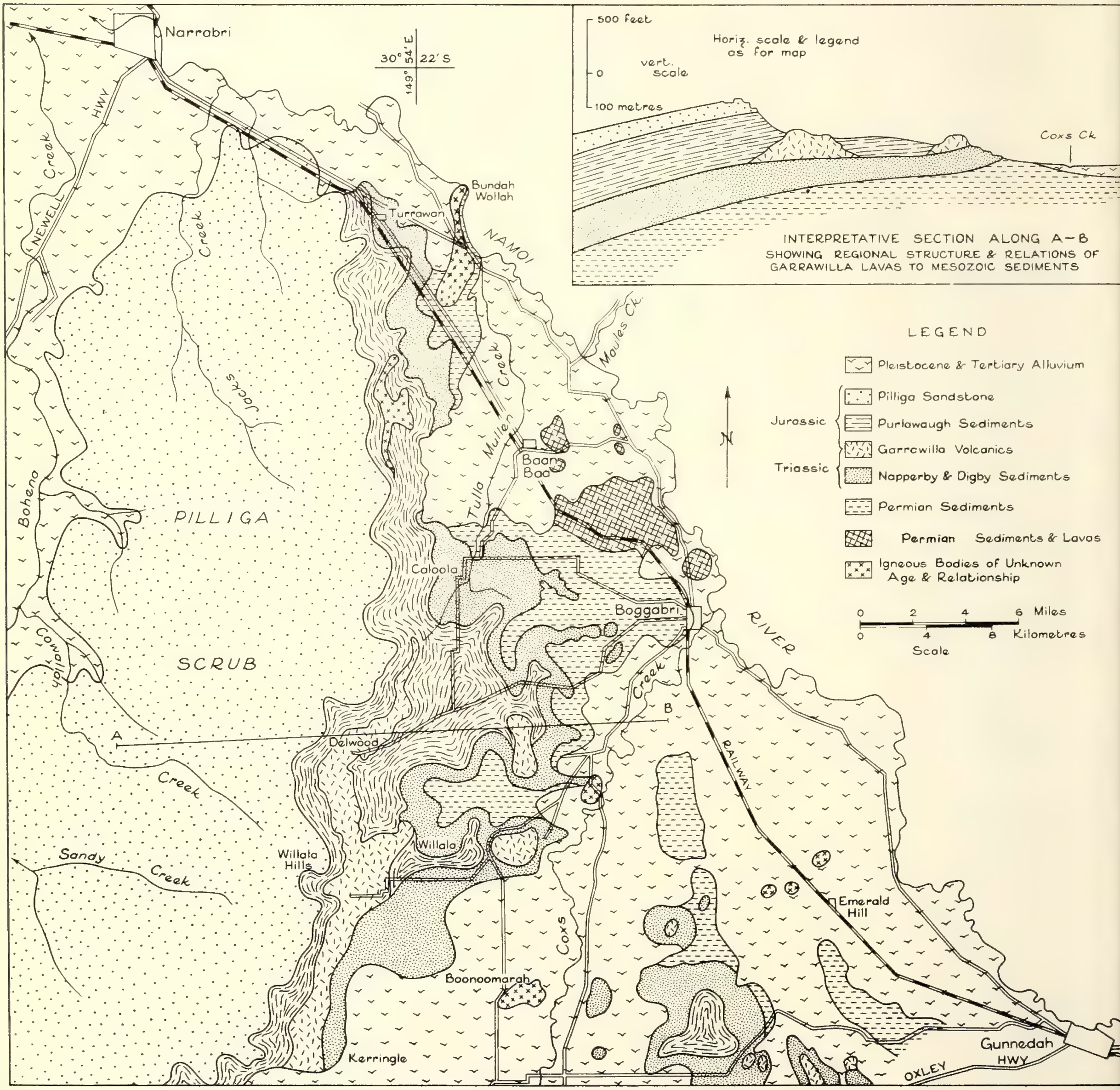

FIG. 1

Geological Map of the Gunnedah-Narrabri District.

original shoreline. It would appear that the Digby Beds become thinner, and the Napperby Beds thicken with distance from the shoreline, although confirmation would require additional sub-surface data.

Field distinction between Triassic Napperby Beds and Jurassic Purlawaugh Beds is based partly on relations of the sediments to the Garrawilla Lavas, and partly on lithological characteristics. As established in the Gunnedah-Coonabarabran region, the horizon representing commencement of extrusion of Garrawilla lavas provides a plane of demarcation between Napperby and Purlawaugh Beds. This distinction is possible in south-eastern parts of the present district, but in central and northern sections, where the lavas are not continuous, and beyond the limits of the flows, differentiation depends on differences in the inherent lithologies of the two groups of sediments. The Triassic Napperby Beds consist mainly of clay shales, sandy shales and soft argillaceous sandstone interbedded with hard calcareous laminated sandstone, all of low iron content, producing light grey outcrops and light coloured sandy clay soils of relatively low fertility. The Purlawaugh Beds also include clay shales, sandy shales and soft argillaceous sandstone, but flaggy calcareous sandstones are absent, and a highly ferruginous "basic" content, undoubtedly derived from the weathering of Garrawilla Lavas, produces yellow-brown outcrops and highly fertile red soils.

The distinction between Pilliga Sandstone and underlying Purlawaugh sediments with interbedded Garrawilla Volcanics presents no difficulty in any part of the district. The Pilliga Sandstone consists of massive course ferruginous grits, with minor shaley lenses. It dips west producing bold yellow cliff-forming outcrops, from beneath which soft Purlawaugh sediments emerge, from south to north, along the eastern side of the well-known Pilliga Scrub which thrives on red-yellow sands, of low fertility, derived by weathering of the ferruginous sandstones.

Garrawilla Volcanics

Basic lava flows of the Garrawilla Volcanics extend into the district from the south, and continue north almost to Caloola, some ten miles west of Boggabri. Outcrops are almost continuous, disappearing only where covered by sandy outwash deposits extending down from elevated hills of Pilliga Sandstone to the west. To the south, between Kerringle and Willala Hills, the outcrop of lavas is situated between the outcrops of Napperby and Purlawaugh Beds, as illustrated in Fig. 1. This is consistent with the occurrence of lavas on the horizon separating the two groups of sediments. North from Willala Hills towards Caloola, the main outcrop of lavas trends away from the outcrop of Napperby Beds into the area occupied by Purlawaugh Beds, and gradually thins out till it disappears a little north of Delwood, as if changing progressively to a higher horizon. To the north-east, between Willala and Boggabri, isolated outcrops of Garrawilla Lavas occur along the boundary between Purlawaugh and Napperby Beds, representing the outcrop of the normal Garrawilla horizon.

The foregoing arrangement of outcrops, together with regional dips to the west, suggested the anomalous situation of two horizons of interbedded lavas ; one on the normal horizon at the top of the Napperby Beds, and another intertonguing with, or transgressing, the Purlawaugh Beds to a position a little below the Pilliga Sandstone. However, as a result of careful field studies of outcrop, structure and topography, it was concluded that erosional residuals of lava flows, resting upon Napperby Beds, were submerged beneath sediments during Purlawaugh deposition. Tertiary erosion has now revealed the tops of the residuals giving isolated outcrops of lavas, some surrounded by Purlawaugh sediments, others by Napperby sediments, and still others on the boundary between the two groups of sediments. This interpretation of relations of Garrawilla Lavas to Triassic and Jurassic sediments, between Boggabri, Willala and Caloola, is illustrated by a section along the line A-B in Fig. 1.

No Garrawilla Volcanics have been established north of Caloola, to as far as Turrawan where alluvial sediments of the Namoi Valley swing west towards Narrabri, concealing outcrops of Mesozoic sediments on the northern side of the Gunnedah-Narrabri district. Deep bores to the west have not revealed the occurrence of lavas either beneath or west of Bohena Creek. In general, it would appear that the area of extrusion of Garrawilla Lavas extended north from the main centres of eruption near Mullaley, along the eastern sides of the Triassic lakes, to the vicinity of Boggabri where much of the lava, in marginal areas, was removed by erosion before subsidence brought it beneath Jurassic sedimentation.

Other Igneous Rocks

In addition to lavas of the Garrawilla Volcanics, there occur throughout the district several outcrops of basic igneous rocks, shown in Fig. 1 as igneous bodies of unknown age and relations. It has not yet been possible to determine the age of these rock bodies, or their relations to surrounding country rocks, owing to low relief and lack of outcrop, but it is hoped that future petrological work and radioactive dating may help.

Alluvial Sediments

Widespread and deep alluvial beds occur along the valley of the Namoi River, from Gunnedah north-west past Boggabri to Narrabri and beyond. West from Gunnedah the alluvium passes round Permian and Mesozoic outliers, between Emerald Hill, Boonoomarah and Mullaley, to become continuous with alluvium of Cox's Creek and the north-western Liverpool Plains.

For the purpose of the present paper, all unconsolidated or partly consolidated sediments dating from as early as late Cretaceous, through Tertiary to Pleistocene and Recent, are shown as undifferentiated alluvium in Fig. 1. There is, however, evidence of alluvium of different ages, in varying degrees of consolidation, and varying modes of occurrence in relation to Tertiary tectonics, providing interesting opportunities for future work in geomorphology.

Acknowledgements

In conclusion the author wishes to acknowledge research facilities provided by the University of Sydney and financial assistance by organizations contributing to the Great Artesian Basin Research Project.

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The Petrography of a Coal Seam from the Clyde River Coal Measures, Clyde River Gorge, N.S.W.

A. C. Cook and H. W. Read

Summary.—The coal is of low bituminous rank. It is only moderately rich in vitrinite but contains significant amounts of exinite. In type it is very similar to a number of coals described from the Greta Coal Measures. The rank of the coal is much lower than that of the Bulli Seam coal in the Illawarra Coal Measures near Wollongong, though it would appear that the maximum depth of cover is similar for the Clyde River Coal Measures coal and for the Bulli Seam in the Wollongong area.

Introduction

This paper describes the results of a petrographic study of a coal seam, belonging to the Clyde River Coal Measures, which outcrops in the valley of the upper Clyde River some 30 miles south-west of Nowra on the south coast of New South Wales (Fig. 1). The results are discussed in relation to some other New South Wales coals.

McElroy and Rose (1962) record that the coal measures were named by David and Stonier in 1891. The coal measures are of Permian age, have a maximum total thickness of 135 feet, and consist of a fresh water sequence of shales, sandstones and thin lenticular coal seams. They unconformably overlie older Palaeozoic rocks and are in turn conformably overlain by the Permian marine rocks of the Shoalhaven Group. The intrusive Milton Monzonite of Permian age (McElroy and Rose, 1962) forms a number of outcrops some eight miles to the east of the coal seam outcrop and Tertiary basalts cover extensive areas to the west and north.

The coal seam described below was sampled at the entrance to an old prospecting adit, located and described by McElroy and Rose (1962) as Section R. At this location the Clyde River Coal Measures are directly overlain by the Conjola Formation. About a quarter of a mile to the south of the adit, McElroy and Rose (1962) show the Clyde River Coal Measures pinched out with the Conjola Formation lying directly on the Lower Palaeozoic rocks. Chemical analyses have been reported by McElroy and Rose (1962) and by Harper (1915) but no petrographic data have been published for any of the Clyde River Coal Measures coals.

The section sampled together with some chemical analyses are shown in Table 2. These

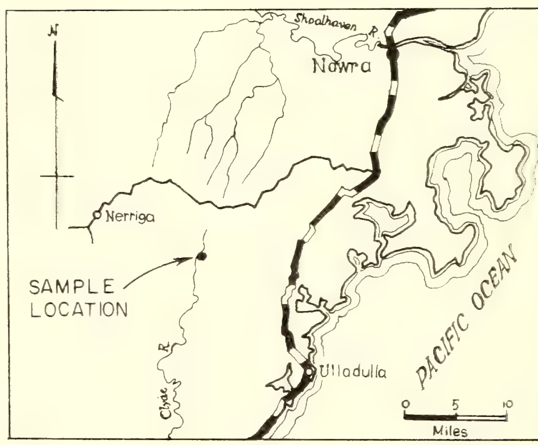

Fig. 1
Locality map.

chemical analyses are of limited value because the samples were somewhat weathered.

Sampling Preparation and Analysis Methods

The coal seam was channel sampled, with each identifiable coal ply and shale ply sampled separately. Grain mounts were prepared for petrographic analysis. Cold setting astic resin was used as the bonding agent and magnesium oxide was used for the final polishing of the grain mounts (Taylor and Zeidler, 1962).

In addition to the coal and shale samples, weighted composite samples were prepared for the seam section, both including and excluding shale bands.

Maceral and microlithotype analyses were made on all the coal samples and vitrinite reflectance measurements made on selected

TABLE 1

Stratigraphy (after McElroy and Rose, 1962)

			Thickness
Permian	Shoalhaven Group	Nowra Sandstone	650′
		Wandrawandian Siltstone	400′
		Conjola Formation	600′
		Yadboro Conglomerate	590′
		Pigeon House Creek Siltstone	160′
			2,400′
	Clyde River Coal Measures		135′

Basement of strongly folded Lower Palaeozoic rocks.

TABLE 2

Clyde River Coal Measures Coal Seam Section and Proximate Analyses

Ply No.	Thickness	Description	Ash % (dry basis)	Volatile Matter % (dry basis)
		Roof: Shale, carbonaceous.		
1	0′ 2″	Coal, mainly dull	13·9	28·7
2	0′ 7″	Coal, mainly dull, Penny band	11·0	30·6
3	0′ 11″	Coal, mainly dull	14·6	26·4
4	0′ 2″	Coal, dull and bright*	11·8	29·4
5	0′ 3¼″	Shale, carbonaceous	73·2	Not analysed
6	0′ 5″	Coal, mainly dull, Penny band, lenses to 0′ 0¼″	15·0	28·3
7	0′ 11″	Coal, dull and bright*	13·7	30·1
8	0′ 5″	Coal, dull and bright*, shaly in part	40·1	Not analysed
9	0′ 7″	Shale, carbonaceous, lenses to 0′ 9″	68·6	Not analysed
10	0′ 2¾″	Coal, dull and bright*	25·4	26·2
11	0′ 4″	Shale, carbonaceous	64·9	Not analysed
12	0′ 8″	Coal, mainly bright*	13·9	30·7
Total	5′ 8″			
		Floor: 0′ 8″ Coaly shale. Water level.		

* The bright layers are very thin and vitrinite rich coal has a silky rather than a brilliant lustre in hand specimen.

McElroy and Rose (1962) record the seam thickness as 6′ 3″ which is approximately the same as the above section. The 0′ 8″ of coaly shale was not sampled and is regarded as the seam floor.

Composite Sample, excluding shale plies 5, 9 and 11:

Ash	16·5%	(dry basis)
Mineral matter	17·5%	,,
Volatile matter	29·5%	,,
Sulphur	1·02%	,,

samples. Approximately 500 points were counted for each petrographic analysis and 40 measurements made for each reflectance profile, except for the lower coal ply and the composite sample on which there were 78 and 84 reflectance measurements respectively.

Maceral analyses were made at a total magnification of 700. Microlithotype analyses were made by the *selon la ligne* method at a total magnification of 300.

Petrography of Coal Seam

See Tables 3 and 4 for maceral and microlithotype analyses.

Vitrinite

The vitrinite content of the coal plies varies from 31% to 73%, averaging 42% for the full section and 52% for the full section excluding shale bands. The vitrinite typically occurs as fine layers and small lenses associated with

TABLE 3
Maceral Analyses

Ply No.	Vitrinite	Exinite	Micrinite	Semi-fusinite	Fusinite	Minerals	Total
1	40	10	20	20	5	5	100
2	58	7	17	10	2	6	100
3	31	10	23	21	7	8	100
4	68	6	12	10	Trace	4	100
5		Shale Band					
6	37	10	25	18	3	7	100
7	64	5	13	8	3	7	100
8	45	4	17	10	Trace	24	100
9		Shale Band					
10	45	10	16	9	Trace	20	100
11		Shale Band					
12	73	5	8	7	1	6	100
Composite including shale plies . .	42	7	19	11	1	20	100
Composite excluding shale plies . .	52	6	19	12	2	9	100
Calculated composite excluding shale plies . .	52	7	17	12	3	9	100

TABLE 4
Microlithotype Analyses

Ply No.	Vitrite	Clarite	Duro-clarite	Claro-durite	Durite	Fusite	Carbar-gilite	Clay	Total
1	8	2	47	29	1	12	1	—	100
2	22	6	49	12	1	6	3	1	100
3	11	3	22	25	14	23	1	1	100
4	36	12	42	5	1	2	1	1	100
5	Silty carbonaceous shale with about 10–20% quartz in the fine sand and silt size ranges.								
6	5	1	55	31	2	5	1	tr*	100
7	21	7	62	3	tr*	4	3	tr*	100
8	1	1	61	4	1	6	25	1	100
9	Clay with 10–20% quartz as in ply 5. Coal mainly as duroclarite, clarodurite and fusite.								
10	7	1	64	8	1	4	12	3	100
11	Similar to ply 9 but coal slightly more abundant.								
12	36	8	39	2	tr*	4	11	tr*	100
Composite including shale plies . .	17	3	38	12	3	7	7	13	100
Composite excluding shale plies . .	20	4	43	9	3	11	8	2	100
Calculated composite excluding shale plies . .	17	5	47	13	3	8	6	1	100

* Trace.

other macerals (Fig. 3) and in places filling cells in fusinite or semifusinite (Fig. 4). The microlithotype analyses show that the major portion of the vitrinite occurs as clarodurite or duroclarite. Some of the vitrinite has a layered or striated appearance, with a lower reflectance than the more massive vitrinite. The two vitrinites, higher and lower reflecting, are considered to be analogous to vitrinites A and B described by Brown, Cook and Taylor (1964).

Some of the vitrinite contains disseminated fine micrinite (Fig. 2).

Exinite

The exinite content varies from 4% to 10%, averaging 7% and 6% for the composite sections including and excluding shale bands respectively. It is present mainly as microspores and leaf cuticles (Fig. 2), with minor resin bodies, rare megaspores and some sporangia.

Inertinite

Micrinite is present generally as small irregularly shaped grains aligned parallel to the bedding, with some larger fusinized resin bodies (Fig. 5) up to 200 microns diameter in places exhibiting a lower reflectance rim. Most of the micrinite present falls into a reflectance range of 1·3% to 3·0%, relatively little occurring with a reflectance close to that of the vitrinite. The maximum reflectance recorded for micrinite was 5·5%.

Fusinite and semifusinite occur mainly as bands and lenses about 100 microns thick in places with cell cavities filled with material of the reflectance of vitrinite (Fig. 4). Cell structures are usually well preserved in the higher reflectance material. Only a few examples of bogen structure were noted in fusinite. The maximum reflectance recorded for fusinite was 3·5%.

Minerals

Mineral matter is represented by clay and quartz with occasional traces of carbonate, apatite and pyrite. The clay is very fine grained and generally disseminated within or between the macerals. Detrital quartz grains

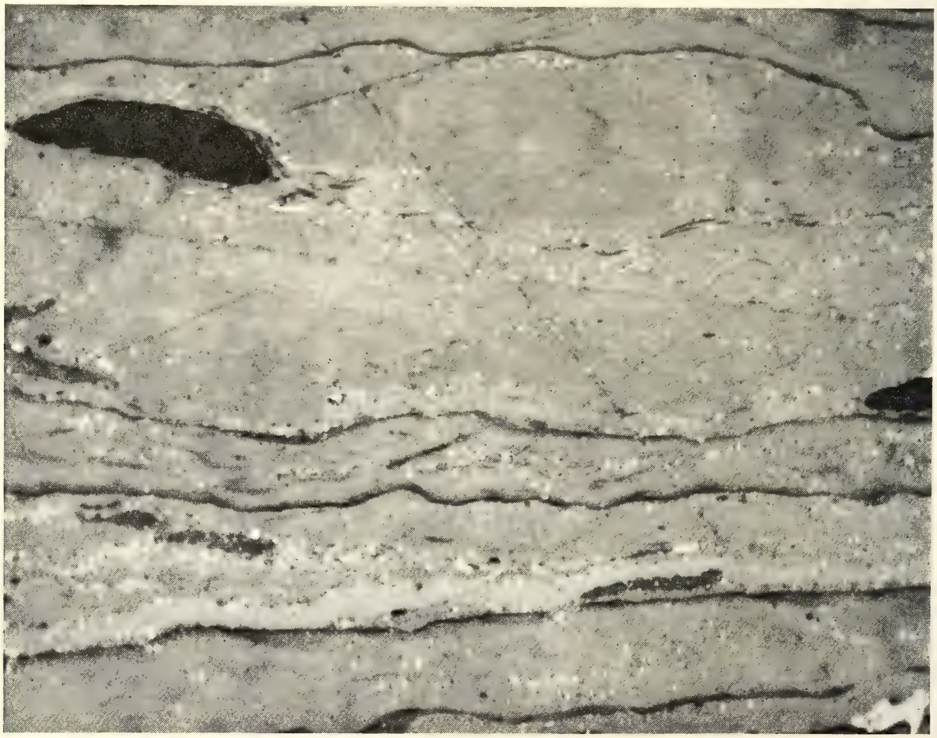

FIG. 2
Vitrinite, grey, with exinite, dark grey, occurring as leaf cuticles and microspores. Reflected light, oil immersion. 700×.

FIG. 3
Thin layers of vitrinite, grey, with micrinite, light grey to white and exinite dark grey. Reflected light, oil immersion. 700 ×.

are abundant at some horizons and range up to 100 microns diameter. The shale bands consist of fine grained clay with 10% to 30% of detrital quartz grains typically about 100 microns in diameter.

Comparison of the Clyde River Coal Measures Coal Seam with Coals from Greta Coal Measures

There is a striking resemblance between the Clyde River coal and coal from the Greta Coal Measures (Table 5). The resemblance is present at all scales from gross hand specimen features down to the fine structure of the vitrinites. Whilst the Greta Coal Measures coals show a range of petrographic composition they all have certain characters in common. These they share with the Clyde River Coal Measures coal described above.

Major similarities noted are :

(i) Overall maceral composition. Although the Clyde River Coal has a lower vitrinite and higher inertinite content than the typical Greta Seam

TABLE 5
Maceral Analyses of Some Greta Coal Measure Coals

Location and Seam	Vitrinite	Exinite	Micrinite	Semi-fusinite	Fusinite	Minerals	Total
Muswellbrook							
Brougham, Upper	60	7	11	15	2	5	100
Brougham, Lower	55	10	10	15	2	8	100
Pinetrees	51	9	12	19	3	6	100
Clyde River	52	7	17	12	3	9	100

FIG. 4
Semifusinite showing scalariform pitting. Cell lumens filled with material of vitrinite reflectance. Reflected light, oil immersion. 700×.

coal (Taylor, 1963), its maceral composition lies well within the range reported for other Greta Coal Measures seams (C.S.I.R.O., 1967) (Table 5).

(ii) The small size of the phyterals gives a very finely layered structure with small fragments of semifusinite, micrinite and exinite intimately mixed (Figs. 3, 5).

(iii) The relative abundance of exinite.

(iv) The abundance of fusinized resin bodies, often of very high reflectance (Fig. 5).

(v) The reflectance profile of the vitrinite, also the general similarity of the vitrinite which often has a finely striated appearance, probably due to the presence of exinite-like material (Taylor, 1965).

(vi) The presence of significant amounts of durite, an unusual feature in N.S.W. Permian coals.

(Note: Durite quoted in analyses of the Bulli Seam (Taylor, 1963) would now in the main be referred to as microite and fusite.)

(vii) Dominance of trimaceral over bimaceral and monomaceral microlithotypes (Table 4).

The Significance of the Similarity between the Clyde River and Greta Coal Measures Coals

The Clyde River Coal Measures have been considered to be a time equivalent if not a southern continuation of the Greta Coal Measures (Harper, 1915). Brown, Campbell and Crook (1968) suggest that the Clyde River Coal Measures might be " somewhat older " than the Greta Coal Measures. This view is supported by Helby (1968) who assigned an Upper Allandale age on the basis of the spore assemblage.

The similarity in the petrography of the coals suggests that the depositional facies were similar in many respects. It is difficult to equate the general sedimentary environment of a small closed basin situated in an isolated depression in the basement with that over the extensive areas in which the Greta Coal Measures were

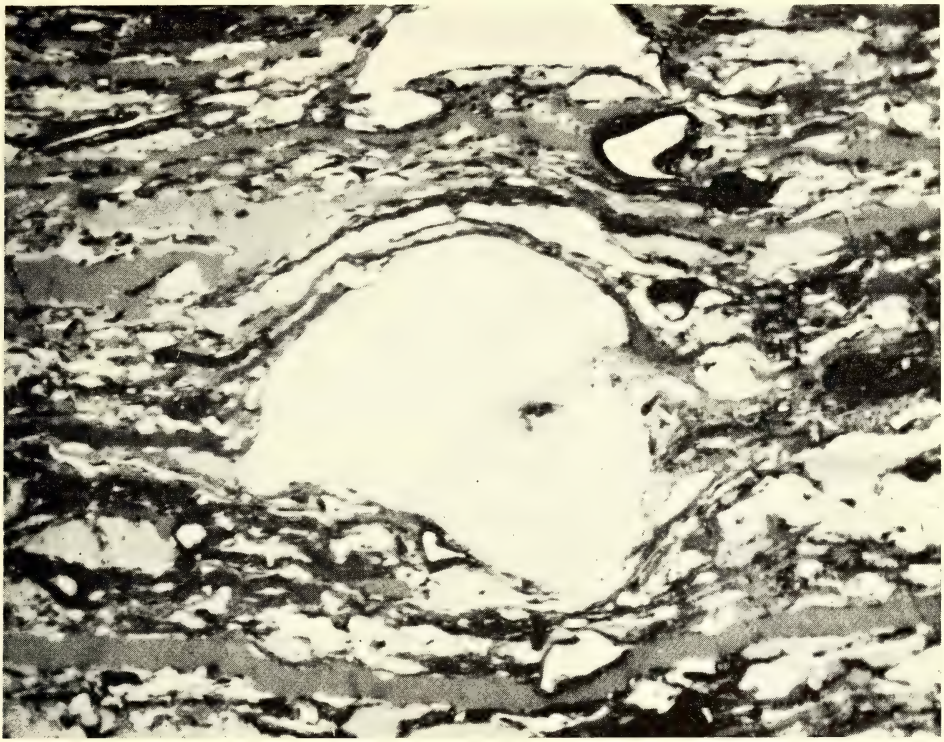

FIG. 5
Durite containing a large fusinized resin body. Reflected light, oil immersion. 700×.

deposited. However, the only dissimilarities between the coals attributable to this difference in scale are the relative abundance of detrital quartz grains in some coal plies and perhaps the greater inertinite content of the Clyde River coal although some Muswellbrook Greta seams have a similar inertinite content. This apparent lack of dependence of the coal type on the size of the coal forming basin is more in accord with an autochthonous origin than the allochthonous origin for the coal seams which Booker on balance appeared to favour (Booker, 1957, p. 40).

In both the Greta and Clyde River Coal Measures coals large plant fragments are very rare. This may be due to greater comminution of plant material than was common later in Permian times but is more probably due to an absence of large tree-like vegetation and an abundance of smaller forms.

The presence of abundant detrital quartz of sand size in certain layers in the Clyde River Coal Measures coal, the absence of brecciated coal, together with the regularity of bedding, makes it difficult to accept the inttinesgre floating raft theory of peat formation put forward by Duff (1967). Currents strong enough to bring in even relatively fine detrital sediment could probably cause disruption of floating rafts of peat, unless they were very firmly anchored. This could produce disturbed bedding analogous to that found at the margins of washouts in British coals (Raistrick and Marshall, 1948, pp. 84-85). As disturbed bedding has not been reported for the Greta coals, nor the Clyde River coals, it seems more probable that the peat constituted a coherent layer which was occasionally inundated by sediment-carrying water. Further, the small size of the phyterals could be indicative of the small types of plants often found in a marsh environment.

An explanation must be sought both for the similarity of these two groups of coals and the differences they exhibit compared with the Newcastle and Illawarra Coal Measures. The presence of marine rocks above the Clyde River

and Greta Coal Measures could be held to account for such features as the locally high sulphur contents but seems unlikely to have influenced the gross petrography of the coals. Climate, by controlling both the type of flora and the peat-forming conditions, can influence the petrographic features. It is therefore suggested that the similarity of the Clyde River and Greta Coal Measures coals is due to a similar climate.

Rank

Vitrinite reflectance measurements were made on six of the coal plies and on the composite sample excluding shale plies (Fig. 6). The maximum reflectance was measured in each case because this is independent of grain orientation. Following Brown, Cook and Taylor (1964), an attempt was made to distinguish vitrinites A and B. It proved to be more difficult to distinguish vitrinites A and B by their appearance for the Clyde River Coal Measures coal than is normally the case for coals of comparable rank. Subjective estimates of a suitable reflectance value for use as a cut off between the vitrinites were made for four samples during the measurement of the reflectance. Figures of 0·79% (composite), 0·79% (ply 2), 0·82% (ply 3), and 0·83% (ply 12) were obtained. Subsequent inspection of the frequency diagrams suggested that 0·80% provided the most natural separation of the higher and lower parts of the reflectance range and this figure was used.

Smyth (1968) suggested that by selecting only the vitrinite occurring as vitrite a less subjective method would result for determining the reflectance of vitrinite A. This procedure did not provide a reliable criterion for the subdivision of vitrinite in the case of the Clyde River Coal Measures coal, since considerable amounts of high reflectance vitrinite occur in bimaceral and trimaceral microlithotypes and conversely low reflectance vitrinite occurs in vitrite. Comparison of Table 4 with Fig. 6 shows, for example, that plies 3 and 6 have very low vitrite contents (11% and 5% respectively) but a relatively high mean maximum reflectance for the vitrinite (0·83% in both cases).

The range of reflectance found in the six plies and the composite sample is 0·79% to 0·85% for the mean maximum reflectance of all the vitrinite suitable for reflectance measurement and 0·82% to 0·86% for the vitrinite A as defined above. The mean maximum reflectance of the vitrinite A in the composite sample, 0·84%, is considered to be the figure most suitable for use as an indication of rank.

Comparison of the Rank of the Clyde River Coal Measures Coal with That of Some Other N.S.W. Coals

The Clyde River Coal Measures coal ($\bar{R}$ max. vitrinite A 0·84%) is of much lower rank than the stratigraphically higher coals of the Illawarra Coal Measures in, for example, the Wollongong area some 80 miles to the N.N.E. where the Bulli Seam vitrinite A has a mean maximum reflectance in the range 1·2%–1·45%.

The rank of coal is generally considered to be a function of the temperature attained during burial metamorphism (Francis, 1960). Increased cover results in increased temperatures and therefore rank. For any given cover rank will be a function of the geothermal gradient. Igneous activity can, by locally increasing the supply of heat, cause a rise in rank (see e.g. Kisch, 1966).

At the sample location the Clyde River Coal Measures have a cover of about 1,800 feet to the top of the Nowra Sandstone. The stratigraphically higher Berry Formation, Illawarra Coal Measures and the Triassic rock units are unlikely to have been in excess of 1,000 feet in total thickness since all of these units thin to the south in the region of Nowra (see locality map, Fig. 1). Therefore, the maximum cover on the Clyde River Coal Measures is unlikely to have been greater than 2,800 feet. The total cover on the Bulli Seam in the Wollongong area to the top of the Wianamatta Group is also unlikely to have exceeded 3,500 feet, a figure of 2,500 feet being more probable.

In the Planet Oil East Maitland bore, Greta Coal Measures coal from 4,635 feet has a vitrinite reflectance of 1·44% (C.S.I.R.O., 1964). The coals of the Tomago Coal Measures which outcrop near the East Maitland bore have a vitrinite A mean maximum reflectance of 0·83% (Taylor, 1968), so that in this case it is possible to associate a change of reflectance from 0·83% to 1·44% with an increment of cover of about 4,000 feet. The difference between the rank of the Clyde River Coal Measures coal and the Bulli Seam in the Wollongong area is almost the same. If the Hunter Valley data is used for the Southern Coalfield an additional 4,000 feet of cover for the Bulli Seam would appear to be necessary to explain this difference on the basis of depth of cover. This in turn would necessitate a long and important episode of post-Wianamatta sedimentation ; an episode of which there is now no trace.

There remains the possibility that the geothermal gradient was much greater in the

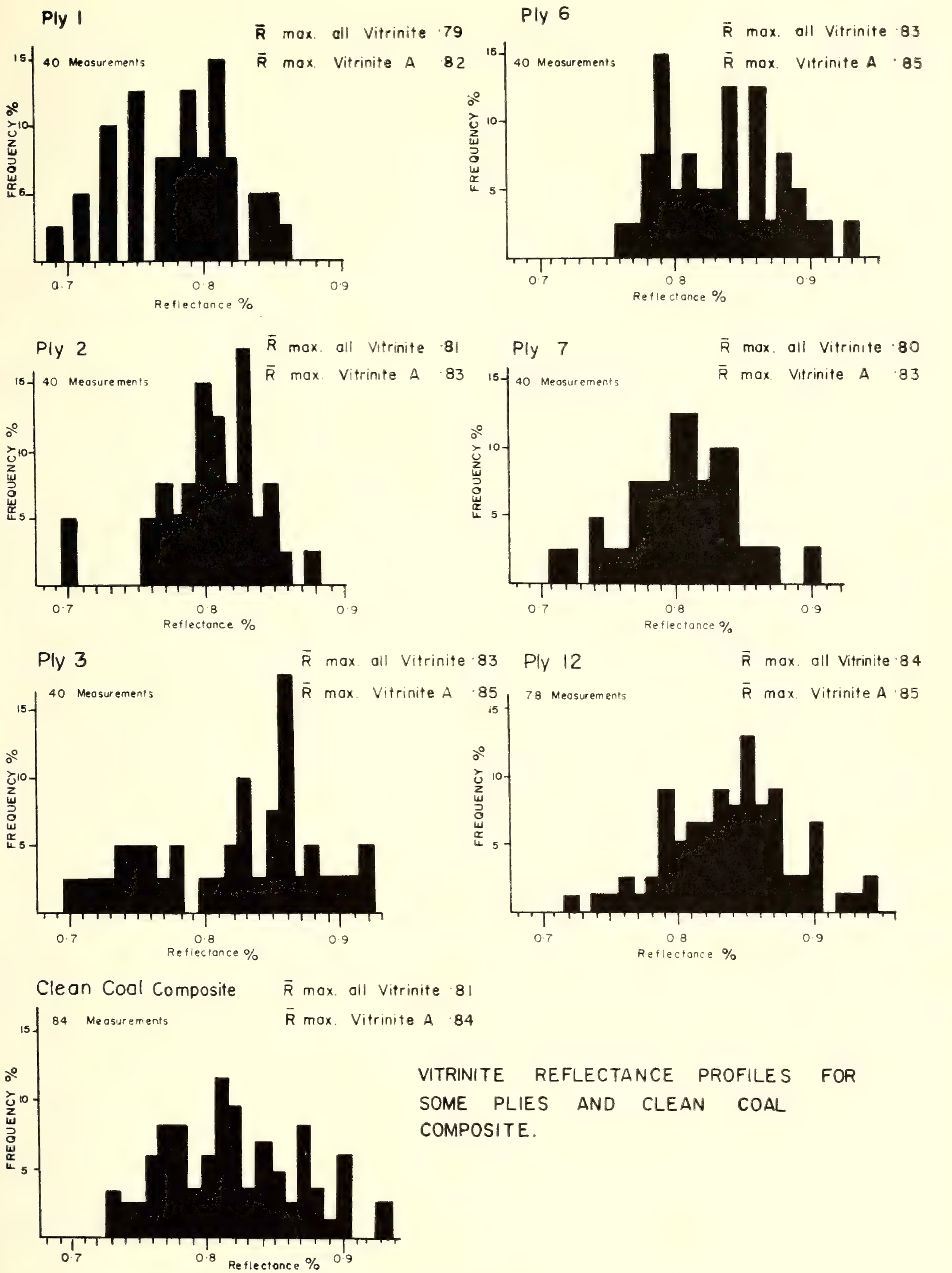

Fig. 6
Vitrinite reflectance profiles for some plies and clean coal composite.

Wollongong area, perhaps due to extrusive and intrusive igneous activity. Any such thermal effect would have to be regional rather than local since, apart from very localized contacts and areas of carbonized coal, the rank of coal in the Wollongong area varies gradually and does not appear to be affected by any of the known igneous bodies. The Wollongong area certainly is affected by post-Permian intrusions and there appears to have been a major area of Permian vulcanicity in the Port Kembla to Kiama area. The rank of the Bulli Seam, however, declines slightly to the south (that is, towards Kiama) from Wollongong (Wilson and Cook, 1968). The Clyde River Coal Measures are not intruded by any igneous bodies but there are extensive areas of Tertiary basalts immediately north and north-west of the Clyde River gorge and there is the large mass of the Milton Monzonite which outcrops about eight miles to the south-east.

It is therefore difficult to explain the difference between the rank of the Clyde River Coal Measures coal and that of the Bulli Seam in the Wollongong area, either on depth of burial or on the relative abundance of igneous activity. To this extent the difference can be held to be anomalous.

Conclusions

1. The Clyde River Coal Measures coal is only moderately rich in vitrinite and contains significant amounts of exinite, mainly microspores. The phyterals are typically relatively small with trimaceral microlithotypes predominating.

2. The petrography, chemical analyses and rank of the Greta and Clyde River Coal Measures coals are closely similar.

3. The similarity of petrographic composition and characteristics between the Greta and Clyde River Coal Measures coals probably reflects a similarity of the types of vegetation which gave rise to the coals. This in turn could reflect a similarity of climate.

4. Although there may have been local zones of allochthonous accumulation in the coal basin, the bulk of the Clyde River Coal Measures coal is essentially autochthonous in origin.

5. The mean maximum reflectance of the vitrinite A is $0 \cdot 84\%$, indicating that the rank of the coal lies in the lower part of the range of bituminous coals.

6. It is difficult to relate the rank of the Clyde River Coal Measures coal to that of the Bulli Seam in the Wollongong area on the basis of maximum depth of cover.

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CONTENTS

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Journal and Proceedings, Royal Society of New South Wales, Vol. 101, pp. 119–127, 1968

The Film Badge Service in New South Wales

A. W. Fleischmann
Radiation Branch, Division of Occupational Health

Abstract.—The article sets out to fulfil five purposes, (1) to give a historical background to the Film Badge Service in New South Wales, (2) to give some details on how the service operates, both scientifically and clerically, (3) to summarize the results to date, (4) to discuss the accuracy of Film Badges in general, and (5) to look at some other methods of personnel dosimetry.

The Film Badge Service in New South Wales commenced in November, 1959, with some 16 organizations and a total of 155 persons actually wearing the badges. By December, 1967, the number of organizations using the Service had grown to 935 with some 2,951 persons actively involved. Figure 1 illustrates this increase as recorded in December of each year for a number of categories of occupations that are self explanatory.

This followed the setting up of a Radiation Branch within the Division of Occupational Health of the Department of Public Health. The Radioactive Substances Act had been given assent on 25th March, 1957, and was promulgated on 6th April, 1959. (Govt. of N.S.W., 1957.)

Previous to this, Film Badges were issued by the School of Public Health and Tropical Medicine who passed their results on to the Division of Industrial Hygiene (later to become Occupational Health) following the inception of the latter department.

The first film badges used in New South Wales, were issued by the Bureau of Physical Services at Royal Prince Alfred Hospital in 1936 and consisted, essentially, of a Kodak DF11 dental film wrapped in paper for additional protection. This was worn for X-ray exposures, and for gamma exposures a small wood cassette was sometimes made up. The badges were not issued as a regular service but rather as a monitor for special situations that may have been inherently hazardous.

Apart from other matters, the Radioactive Substances Act defines the Maximum Permissible Dose and it is the primary purpose of Film Badges to determine what proportion, if any, of the maximum permissible dose a person acquires while exposed to ionizing radiation. These permitted maxima are summed up in Table 1, which is an extract from the Regulations under the Act. Before going into details of the Film Badge Service, some of the units of ionizing radiation dosage will be defined for the benefit of readers not familiar with this particular field.

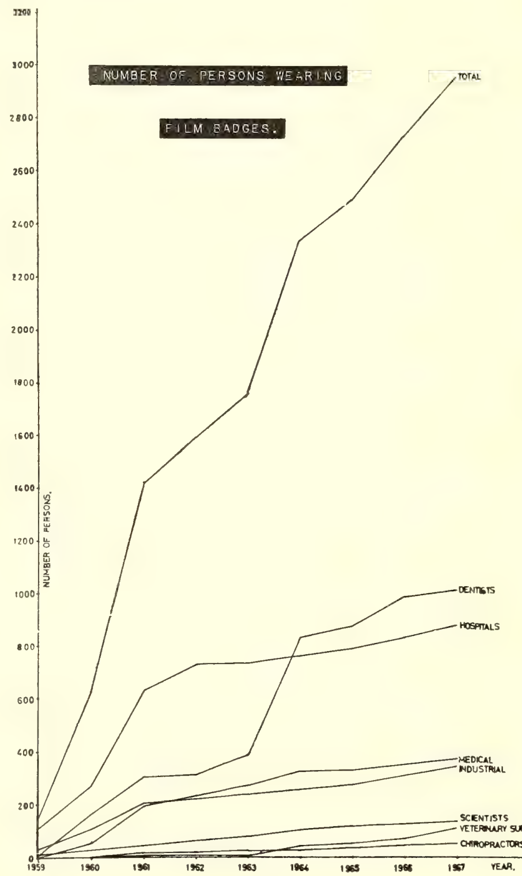


Fig. 1
Increase of Film Badge Usage
(Department of Public Health)

Definitions. (U.S. Dept. of Commerce, 1968)

Curie (*c*) : The quantity of a radioactive nuclide in which the number of disintegrations per second is $3 \cdot 700 \times 10^{10}$.

Roentgen (r) : An exposure dose of X- or γ-radiation such that the associated corpuscular emission per $0 \cdot 001293$ grams of air produces, in air, ions carrying 1 e.s.u. of quantity of electricity of either sign.

Note: Since 1 e.s.u. represent $2 \cdot 08 \times 10^9$, ion pairs, the r corresponds to $1 \cdot 61 \times 10^{14}$ ion pairs per gram of air. Also an average of $32 \cdot 5$ eV of energy is required to produce an ion pair and hence the roentgen is equivalent to an absorption of $5 \cdot 24 \times 10^{13}$ eV, or about 83 ergs ($1 \text{ eV} = 1 \cdot 6 \times 10^{-12}$ ergs) per gram of air.

Rad : The unit of absorbed dose and equal to an absorption of 100 ergs/gram, of absorbing substance. This latter need not be air.

Roentgen–equivalent–man (rem.) : Biological measure of absorbed dose. The absorbed dose of any ionizing radiation which has the same biological effectiveness as one rad of X-radiation with average specific ionization of 100 ion pairs per micron of water, in terms of its air equivalent, in the same region (this is approximately equivalent to the effect of 200 k.v.p. X-rays) (*B.J.R.*, 1955).

$$\text{Dose (rem)} = \text{Dose (rad)} \times \text{R.B.E.}$$

where

R.B.E. = Relative Biological Effectiveness.
= the inverse ratios of the energy absorptions of different radiations which produce equal biological effects.

Some typical R.B.E. values are (Appleton *et al.*, 1960) :

X- and γ-radiation .. .. R.B.E. =	1
Thermal neutrons	2·5
Fast neutrons	10
Protons	10
Naturally occuring α-radiation.	10
Heavy recoil nucleii	20

Table 1

Maximum Permissible Doses

Extract from the Regulations under the Radioactive Substances Act, 1957, No. 5 and Including Amendments, 1962, No. 245 and 1963, No. 112 (Government of N.S.W., 1957)

Categories	Maximum Permissible Doses		
	Gonads, Blood Forming Organs and Lenses of the Eyes (for " whole body " exposure)	Skin and Thyroid Gland (for " whole body " exposure)	Skin, Deeper Tissues of Hands, Forearms, Head, Neck, Feet and Ankles
Radiation Worker over 18 years of age.	5 rem per year or 3 rem per 13 weeks from external and/or internal sources.	8 rem per 13 weeks from external sources only.	20 rem per 13 weeks, but not more than 3 rem to the lenses of the eye over the same period.
Radiation Worker over 16, but under 18 years of age.	1·5 rem per year, external or internal radiation.	3 rem per year, external or internal radiation.	
Occupationally Exposed Workers.	1·5 rem per year, external or internal radiation.	3 rem per year, external or internal radiation.	
General Population.	0·5 rem per year.		

Considerations in Assessing Radiation Dosages with Film Badges

Since there is a considerable difference between the nature of a film emulsion and human tissue there is also a corresponding difference between the response of film and of tissue to ionizing radiation. This difference is not only one magnitude but also of energy dependence. Further, there is a lack of linearity in the relation between the exposure to a particular type of radiation and the corresponding photographic density.

For this reason the dose is usually measured in rads and then, at least in principal, it can be translated to an absorbed dose by means of conversion factors which allow one to arrive at the R.B.E. dose (as defined), rems.

Another consideration is that some organs are more sensitive than others to radiation and for this reason the Maximum Permitted Dose is weighted in favour of whether the exposure is " whole body " or only to extremities, such

as hands or feet. These considerations and the nature of the particular source of radiation serve also to determine the location of the film badge on the wearer's body. In some cases, more than one badge may be worn at the same time.

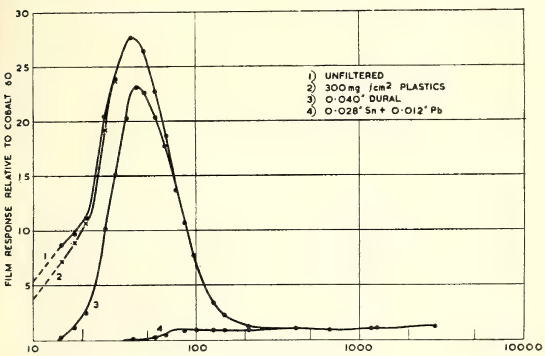


FIG. 2

Response of photographic film to various photon energies, all for the same dosage (Heard and Jones, 1965)

Figure 2 shows the response of a photographic emulsion to various photon energies. It also illustrates the effect of the various filter sections used in film badges.

The Badge

Generally the field to be monitored contains different types of ionizing radiations at a variety of energies. Since, from Fig. 2, these divers energies cause different effects on the film for the same dosage, one can only hope to calculate a correction factor to relate the exposure to the density of the film. For this reason, a number of filter sections have been incorporated in the badge and Fig. 2, also shows the response of the films behind the various filter sections used, while Fig. 3 and 4 show the R.P.S. (Radiological Protection Service, Sutton, U.K.) and the A.E.R.E./R.P.S. (Atomic Energy Research Establishment, Harwell) badges respectively.

A set of filters commonly used for normal photon monitoring are (1) plastic with a density of 300 mg./cm.^{2}, (2) plastic plus a 0·040″ duralumin filter, (4) plastic plus 0·028″ tin plus 0·012″ lead, (5) an open window.

In the earlier R.P.S. holders the filter section were adjacent to one another (Fig. 3) and it was found that there was an error introduced in that radiation passing through the tin filter was being scattered into the dural region and vice versa; and, further, there were insufficient filter sections to allow an adequate dosage formula to be developed. The later A.E.R.E./R.P.S. holder overcame this by placing a cadmium filter between the dural and the tin and also improved the performance of the badge by using two different thicknesses of plastic filter sections. The cadmium would, of course, still cause side scatter but due to its lower atomic number not to as great an extent.

Apart from the one use mentioned above the cadmium also fills the function of a slow neutron monitor.

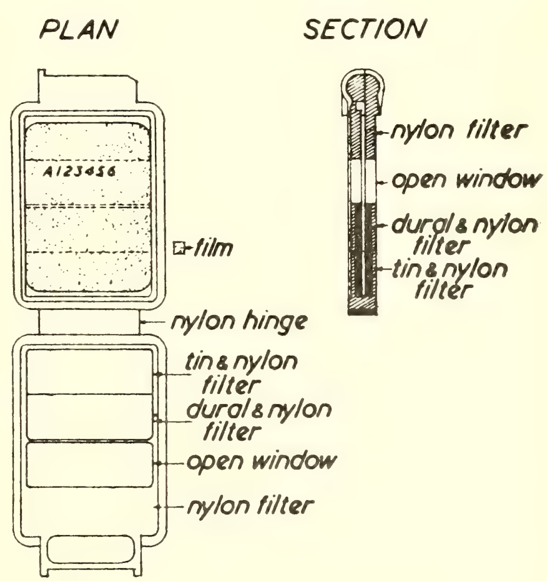
For the A.E.R.E./R.P.S. holder a formula has been developed to cover (X + γ) photon radiation and using a special Kodak Radiation Monitoring Films. With D to represent the apparent dose behind each filter section, we have:

Photon dose D to Badge=

$$\left[D_{\mathrm{tin}} + \frac{D_{\mathrm{Dural}}}{50} + \frac{D_{300} - D_{\mathrm{Dural}}}{10}\right],$$

which is effective over the energy range 15 keV to 2 MeV (Heard and Jones, 1965).

This latter badge is coming into general use in place of a variety of badges previously used. In New South Wales, the R.P.S. holder is at present being used concurrently with the A.E.R.E./R.P.S. one, but as more of the latter become available, it will replace the former.



The film holder designed by the R.P.S. consists of a plastic case with two pairs of metal filters

FIG. 3

The R.P.S. Film Badge (Heard and Jones, 1965)

Although neutrons can be monitored with the new badge, there has never been a real problem outside of atomic energy research establishments, since very little industrial use is made of them. At present there are only two or three commercial neutron sources in New South Wales ; these being used in portable soil moisture meters.

THE FILM

Since the degree of darkening is dependent on dose, though not in a linear manner, it is clear that the larger a range of optical densities the film can cover the larger will be the range of dosages it can record with any degree of accuracy.

For this reason, Personnel Monotoring Films frequently are either of the type that have two emulsions on the one acetate base or they consist of two separate single-emulsion sheets in the one pack.

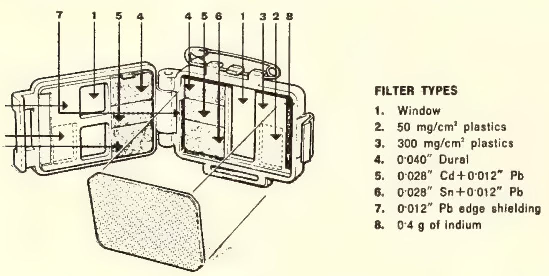


FIG. 4

The A.E.R.E./R.P.S. (Heard and Jones, 1965)

In each case, one emulsion is generally of high sensitivity so that, for example, a dosage of 1 rem of γ-radiation will cause a net density of 3, while the other is a low sensitivity emulsion in which 100 rem will cause a net density of about 2.

Various combinations of measurements are used. In the twin emulsion case, most measurements are made through both emulsions together and only for apparently high dosages is the high sensitivity emulsion stripped off and measurements are made through the remaining one. This is the more convenient method since only one film instead of two has to be developed and, in any case, most dosages are relatively low, this making it rarely necessary to use the slow emulsion.

The films are 3 cm. $\times$ 4 cm. : which is the same as dental X-ray films. As a matter of fact, for many years, dental films were used in Film Badges. The emulsions vary in thickness from 2 to 5×10^{-3} cm., depending on the manufacture.

Mechanics of the Film Badge Service

The Film Badge Service can be divided into two distinct categories as far as its actual operation is concerned. On the one hand, there is the purely clerical side which is concerned with the sending and receipt of films and also with the recording of results, while on the other hand, the Physical side of the service is concerned with calibrating and developing films, measuring density corresponding to the various filter sections and calculating the radiation dosages.

FIG. 5

Developing the films

As far as the sending and receipt of films is concerned, this has been automated as far as possible by use of items such as addressograph machines to print organizations names and addresses on to envelopes and assessment sheets ; assessment sheets backed with copying ink to simplify carbon copying ; visible index card systems with plastic signs to indicate who should receive films next, when the last films were returned, and other necessary information.

The developing of films is carried out under rigidly controlled conditions of temperature, solution quality, and agitation, and about 300 films are developed twice a week. After this,

each film has an identification code stamped on it to record the week in which the film was developed, the year and a wearer's identification number. Next, the density of the various filter sections is measured and recorded on a measuring sheet prior to the calculation of actual dosages.

Every batch of new films is calibrated for a variety of dosages against a Co-60 standard source (Fig. 7) and also for a variety of X-ray energies. After a calibration for the particular

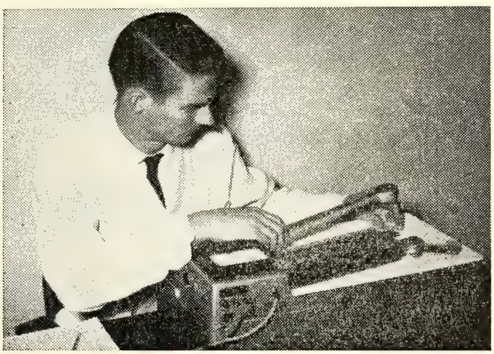


FIG. 6
Measuring the density of films

batch of film has been carried out, it is sufficient to calibrate with Co-60, and the X-ray exposures are purely made for purposes of checking previous results. New, unused films, are sealed in plastic tubing together with silica gel, and are stored in a refrigerator until required.

Results to Date

While the dosage of radiation received by a person in the course of his duties may fluctuate somewhat, the general approach is to look for one or more of three possibilities in the light of limits set by the maximum Permitted Dose Rates as specified by the Radioactive Substances Regulations.

These considerations are (1) the whole body dose rate approaching, or in excess of 3 rem in 13 weeks or 5 rem per year, which classifies it as an Excessive Dosage (Regulation 3) ; (2) the whole body dosage known or suspected to exceed one rem in one week, or 3 rems in one month which again is an Excessive Dosage (Regulation 6 (2) (*b*)) ; (3) the dosage simply higher than the average expected dose.

Although a number of radiologists, medical radiographers and veterinary surgeons have on occasions recorded Excessive Doses the majority, by far, have occurred in the field of industrial radiography. For this reason, Cumulative Dosage cards are kept for all Industrial Radiographers and for a few people in the other categories shown in Fig. 1. Over a period of 6 years the cumulative dosages for industrial radiographers have been as follows :

TABLE 2
Cumulative Dosages for Industrial Radiographers

	Dose Range (rem)	0–1	1–2	2–3	3–4	4–5	Over 5	Total
1962	Number of persons	27	9	5	5	2	1	49
	Percentage of total	55	18	10	10	4	2	—
1963	Number of persons	34	6	6	3	1	5	55
	Percentage of total	62	11	11	5	2	9	—
1964	Number of persons	51	6	5	2	3	1	68
	Percentage of total	75	9	7	3	5	1	—
1965	Number of persons	61	7	2	3	1	4	78
	Percentage of total	78	9	3	4	1	5	—
1966	Number of persons	61	10	6	2	1	6	86
	Percentage of total	71	12	7	2	1	7	—
1967	Number of persons	73	9	1	4	1	1	89
	Percentage of total	82	10	1	5	1	1	—

It is noteworthy that although the number of industrial radiographers has increased by 90% over the period, the percentage dose distribution has remained substantially constant as a result of increased precautions and improvement of equipment.

Industrial radiographers are particularly likely to receive high dosages of radiation because (1) the nature of the work may make adequate shielding difficult, (2) it is not always possible for the operator to move far away from the exposed source, (3) they use comparatively large radioactive sources or high voltage X-ray machines, and (4) they are generally totally unskilled operators who have been given only the most rudimentary instructions. The final

point is probably the most important one, and it is hoped to improve this matter in the near future by the introduction of an Industrial-Radiography course. Nearly all other people working with sources of ionizing radiation have had at least some training which will acquaint them with the properties and safe handling of sources of Ionizing Radiation. It is significant that of 12 " Radiation Incidents " in New South Wales over the period April, 1956 to October 1964, ten involved industrial radiographers (Fleischmann, 1965).

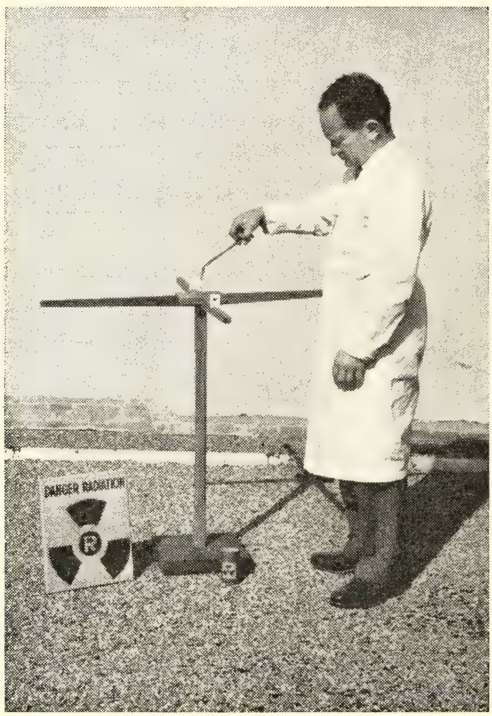


Fig. 7
Calibration of films with Co-60.

Accuracy of Film Badges

A number of experiments have been carried out by a variety of personnel to determine the accuracy of the Film Badge method of dose assessment. The problem has been approached in two ways.

On the one hand, a central organization has subjected a number of badges to a variety of dosages at various energies and has then required some commercial or governmental bodies to assess the dosages. On the other hand, a number of controlled experiments have been carried out where each *facet* of the film badge service has been examined, and on estimate of accuracy and reliability arrived at.

In February, 1965, Gorson, *et al.*, at Jefferson Medical College (U.S.A.) ordered thirty film badges from each of 12 suppliers and at the same time the Radiation Safety Officer at the University of Pennsylvania ordered 28 badges from each of 11 suppliers (the same suppliers being involved in each case). The companies were informed that the badges would be exposed to X- and γ-ray exposures only, and to mixtures thereof. The badges were exposed to γ-rays from Co-60 and Ra-226 and X-rays in the H.V.L. (Half Valve Layer) range 1·4 mm. Al to 3·3 mm. Cu. A number of duplicate exposures were also made.

To quote the authors (Gorson *et al.*, 1965) :

" Results showed a considerable range in both accuracy and consistency among the 12 companies tested. The percentage of the reported values in error by more than $\pm 50\%$, ranged from 7 to 50. The percentage of duplicate exposure readings differing by a factor of 1·5 or more ranged from 0 to 75. Most companies were considerably more successful in evaluating exposures to Co-60 and Ra-226 than they were in reporting the exposures to X-rays on to mixed X- and γ-radiations ".

The paper does not describe the actual form of any of the badges and the types of films used by the various suppliers, but the A.E.R.E./R.P.S. badges with British Kodak RM film would certainly not have been included since neither existed at that time.

In another paper, also in 1965, the School of Medicine at the University of Miami (Menker and Dauer, 1965) acquired film badges from 16 companies in the U.S.A., exposed them to X- or γ-radiation, but not to mixed radiation, and then asked the companies to make a close assessment. They also informed the companies of the type of radiation that each film received. The films were also stored under carefully controlled conditions of temperature and humidity. The percentage deviation from the correct dose found in this survey was, for each type of radiation, in the range (quote) :

" Radium 226	—72% to + 50%
Cobalt 60	—86% to + 52%
250 K.V.P. X-rays	—62% to + 119%
80 K.V.P. X-rays	—63% to +2635% "

No two companies had used the same type of film holder in this test. Thirteen companies used various types of plastic holders and three companies used metal badges.

It is clear from this survey that the companies do not go anywhere near the $\pm 20\%$ that most

of them advertise and actually have trouble staying in the range ±50%. It is remarkable that the γ-radiation assessment should be so inaccurate when one considers that most films are calibrated with γ-radiation, and hence there is no need to use the filters to determine an X-ray correction factor. It is also regrettable that the greatest range of error is in the 80 K.V.P. (Kilo Volts Peak) range which is that used for most medical diagnostic radiography.

The next series of experiments was carried out by H. Brodsky and others for γ-radiation dosage assessment only, over a period of time in 1963 and was reported in *Health Physics* (Brodsky *et al.*, 1963, 1965 ; Kathren, 1963). These workers made an experimental study of the various sources of error that are likely to influence the assessment. These include such factors as (1) temperature, (2) humidity, (3) how often the films are replaced, (4) how long they are stored, etc. They also found that most of the serious errors were also applicable to other systems in some respects. Under ideal conditions, they found that the assessment should be accurate to ±20%.

More recently in 1965, a survey was carried out in Britain to compare the A.E.R.E./R.P.S. badge with an earlier metal badge used by the Radiological Protection Service. This experiment was performed by Langmead and Adams (Langmead *et al.*, 1967) and essentially they compared tests carried out on the new badge plus film with tests carried out on the older badge in 1961. Both sets of experiments were carried out on β-, γ- ; X- and mixed radiations.

The results of the two experiments were summed up in a table, which is reproduced here :

TABLE 3

Summary of Accuracy attained in the two Experiments

Range of Accuracy (±%)	1961 Experiment pressed tin-plate badge (percentage of 94 assessments)	1965 Experiment A.E.R.E./R.P.S. badge (percentage of 84 assessments)
0–20	63	70
21–40	16	19
40	21	11

It is clear that the newer badge offers a greater degree of accuracy and that, in particular, the number of assessments, out by more than 40%, has been greatly reduced. These results are further pleasing in that, in this experiment, both mixed radiation and γ-radiation were included.

In New South Wales, the Film Badge Service has been checked in two ways. One is by asking a number of operators to wear pocket dosimeters alongside their film badges, and the other is by exposing films to a variety of dosages and types of radiation and at the same time measuring the dosages on a calibrated standard dosimeter.

The former method is, of necessity, inaccurate in that one relies on an instrument (the dosemeter) whose qualities and accuracy maybe unknown, and also on unskilled persons who are asked to daily record the readings on the Pocket Dosimeter. Further, the devices have to be recharged from day to day and this, coupled with sources of error in reading a difficult scale, makes the method only a rough check.

The second method, that of comparing films with standard dosemeters, has been carried out on a number of occasions. Experiments carried out in the Division of Occupational Health using High Energy X-rays and a source of Ir^{192} on both the R.P.S. and the A.E.R.E./R.P.S. holder have shown that for a single type of radiation pure X-ray or purely γ- the badges are accurate to the extent that they read 15% to 20% low but for a mixture of X- and γ-rays they read up to 40% to high. The interpretation of X-ray dosage in this latter case is accurate to within 10% (low, as before) but the γ dosage is over 100% too high. The cause for this is that the harder X-rays are of sufficient energy to penetrate the tin filter and cause an over estimate exaggeration of the apparent γ-dosage. The formula proposed by Heard and Jones (1965) overcomes this error and produces a gross assessment as against a separate X-ray and γ-ray dosage but to date we have not had the opportunity to check this because we have not been able to obtain the same films as the ones they used.

Other Methods of Dosimetry

Another type of dosimeter often used in conjunction with film badges is known as the " Pencil " or " Pocket " Dosimeter. As its name implies, it is shaped more like a propelling pencil, and is worn clipped on to the operator's pocket lapel.

It operates on the " gold-leaf electroscope " principal in that charging the dosimeter induces a charge on to a fibre, which causes it to move away from a second electrode inside the chamber. Ionizing radiation causes the change to leak away and the fibre tends to return to its rest position. As it returns, it moves axial to a

graduated scale in the focal plane of a lens system, and the dosage can then be read off by looking through the instrument.

As mentioned, Pocket Dosimeters are sensitive to heat and humidity and also to mechanical damages. They also have the disadvantage that they (*a*) are relatively expensive, (*b*) require a charging unit, which is also expensive, (*c*) do not provide a permanent record of their readings (whereas Film Badges are always available for reassessment) and (*d*) they are made of relatively heavy metal, which in itself will act as a filter to the radiation, and will effect the " energy dependence " of the response, particularly in the lower energy ranges.

A more recent addition to the field of Personal Dosimetry is the Thermoluminescent Dosimeter. This relies on the principle that some crystalline substances store the energy of absorbed ionizing radiation and release it as light when heated. The dosimeter, then, consists of (1) the powder, which is commonly lithium fluoride (LiF), (2) a device to weigh out the powder, (3) the dosimeter which contains the powder either in a glass or plastic phial or on a metal surface, and (4) the dose reader and print-out mechanism.

Thermoluminescent dosimetry systems have the great advantage that their dose responses are substantially energy independent, and that they suffer little fading with time. The main disadvantage is that of initial cost and that a direct substitute for the film badge has not been developed. By this latter point, it is meant that generally the Thermoluminescent Dosimeter is used as a dose reader in radiation therapy procedures. Most personnel dosimeters developed to date are similar in form to the Pocket Dosimeter, where the inner element has been replaced by a glass phial containing the thermoluminscent powder. The combination of metal case and glass phial would seriously impair the ability of the device to measure X-ray dosages. One organization has developed a flat metal plate which contains the powder in a recessed section but this is still in the developmental stage.

In spite of the above problems, which may have been solved by now, the main obstacle is, as mentioned before, that the cost of setting up and maintaining such a system is very far in excess of the same two factors for a film-badge service.

Other methods of dosimetry will not be mentioned here since they are mainly designed for measuring large or massive dosages and rarely are capable of going below 1 rem.

Concluding Notes

The radiological Advisory Council (N.S.W.) has recently decided to adopt a recommendation made by the I.C.R.P., that " workers who have been identified as being in conditions of work such as that their exposure is most unlikely to result in doses exceeding 30% of the annual maximum permissible doses, individual monitoring and special health supervision are not required. For these persons, monitoring of the working environment will usually be sufficient, even though in some cases individual monitoring may be desirable, for example, to obtain statistical information on the exposures " (Recommendations I.C.R.P., 1965).

The conditions under which this recommendation is to be applied in New South Wales, will be that (1) the organization must consistently record less than 30% of the maximum permitted dose, (2) the organization must have been using film badges for at least two years, and (3) annual inspections of the premises must be carried out.

This change will considerably reduce the number of persons wearing film badges in New South Wales. At present, for example, about 900 dentists are wearing film badges and all three of the above conditions apply to most of them. Other categories of workers will be affected to a lesser extent.

Consideration is also being given to the use of computers. This has particular reference to the new A.E.R.E./R.P.S., holder, where, as previously shown, a fairly straight forward formula exists to evaluate dosages. This formula is further aided by short cut steps that allow one to avoid making numerous calculations if the measured densities are below predetermined values.

The use of computors would be aided by having the output from the densitometer connected directly to a tape printer via a digital voltmeter, then the densities could feed straight to a computor once the measurements are completed and the final print out can be so arranged that it can be sent directly to the person concerned. It is not a difficult task to organize the programme to give any required statistical information, such as how many persons in each category received film badges, how many high or excessive dosages have been received, etc.

These changes are still in the planning stage and could considerably simplify the system if implemented.

The author wishes to thank the Director-General of Public Health for permission to publish this article, and Mr. R. deVries, of the Division of Occupational Health, who took the photographs.

Summary

It was endeavoured to give a general survey of the Film Badge Service in New South Wales as it exists to-day. The service is still increasing in the number of persons and organizations served, in spite of the removal of numerous organizations that consistently show low dosage returns. At the present time a computer programme to eliminate all the calculations, and much of the clerical work, has been prepared and it is hoped to commence the use of this in the very near future.

The results given show that, with improved equipment and techniques, industrial radiographers are tending to fall into lower accumulated dosage groups.

In the discussion of the accuracy of Film Badges it is seen that there is little point in quoting an accuracy of better than 20%, particularly, in cases such as ours, where this is no control of the actual handling and usage of the films and the radiation to which the films have been exposed is only known approximately.

In closing it is indicated that a thermoluminscent dosimetry system would be more accurate than a film badge one, but consideration of economics make it unlikely that a change to this system will occur in the near future. Further there is some doubt on whether the increased accuracy would really be worth the expense.

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A Tesselated Platform, Ku-ring-gai Chase, N.S.W.

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Abstract—An unusual sandstone platform consisting of patterned joint-blocks is described. Although reminiscent of columnar jointing, the " columns " do not continue vertically into the rock. Thin section examination shows little evidence of contact metamorphism. The patterns are considered to be due to metamorphic processes although no igneous intrusion crops out in in the vicinity ; however, there is a possibility that they could be of sedimentary origin.

Columnar jointing in the Hawkesbury Sandstone has been recognized at a number of localities, of which North Bondi and West Pymble (Curran, 1899 ; Morrison, 1904 ; Sussmilch, 1914 ; Osborne, 1948) are perhaps best known. Following a query from Mr. J. Pierman of Sydney Teachers' College, I visited an area in Ku-ring-gai Chase National Park adjacent to the West Head road (locality 1, Fig. 1).

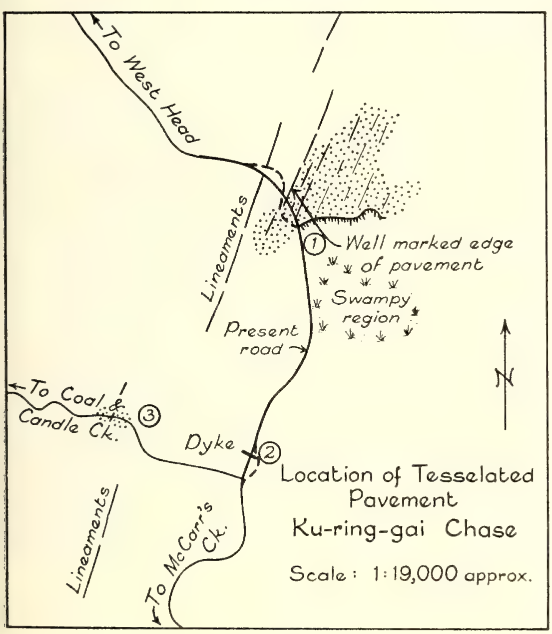

Fig. 1—Locality sketch map.

This area was studied by Campbell (1899), who recorded aboriginal carvings, but he did not comment on the unusual character of the sandstone. At least three separate but closely adjoining areas at this locality are covered by patterns reminiscent of columnar jointing. However, in most cases the " columns " do not appear to continue vertically through the rock for more than a few feet.

The best exposed of the areas is an undulating platform approximately 500 ft. $\times$100 ft., immediately adjacent to the West Head road (Fig. 2). The other areas of comparable size lie to the east and north-east. There are smaller areas (*a*) west of the road at the same locality, and (*b*) on the Coal and Candle Creek road (locality 3, Fig. 1).

Although the phenomenon may possibly be attributed to contact metamorphism, the outcrops are not noticeably hardened as at North Bondi, and thin section examination shows no sign of recrystallization of the quartz grains. Thin sections of altered sandstones close to intrusions at Gladesville, North Bondi, West Pymble, Bundeena and Hurstville show marked changes along grain boundaries of quartz which are not evident in any of three samples from the West Head road site, but incipient alteration of kaolinitic material is similar in all slides. No intrusive rocks have been found to crop out adjacent to the pavements, but there are several large lineaments which may be weathered dykes visible on the aerial photograph of the region (Broken Bay, N.S.W., Run 9, 236–5036)* trending approximately 30°. No dyke material has been found in these and there is no increase in the number of joints adjacent to the lineaments. The nearest visible dyke, trending approximately 290°, crops out at locality 2, Fig. 1. The area immediately south of the

* Photographs on this run have north points incorrectly marked pointing south.

Fig. 2—View of platform looking south-west. The elongate " columns " in the foreground are gradually replaced by uniform five-, six- and seven-sided blocks.

pavements at locality 1 is a low-lying swampy area which could conceivably contain igneous material in a neck-like intrusion.

The north-western edge of the main jointed platform coincides precisely with the edge of a channel sandstone. This channel is clearly exposed in the main road cutting (Fig. 3), where it overlies a very ferruginous sandstone. The eastern edge is not so clearly exposed. Along the base of the channel a thin layer (maximum 3 in.) of soft clay occurs. Columnar jointing is not apparent in the rocks exposed on the east face of the road cutting, but there is some suggestion of columnar development on the west side where only the ferruginous sandstone occurs.

Variations in the patterns in area 1 are shown in Fig. 2 and in Figs. 4 and 5. There is a clear change in dimensions and shape of the patterns along the platform, possibly related to the position of the postulated heat source but also affected in part by the undulations of the surface and the character of the sandstone. Near the north-western edge of the channel, which is sharply defined by a low cliff line, the patterns appear to dip inwards towards

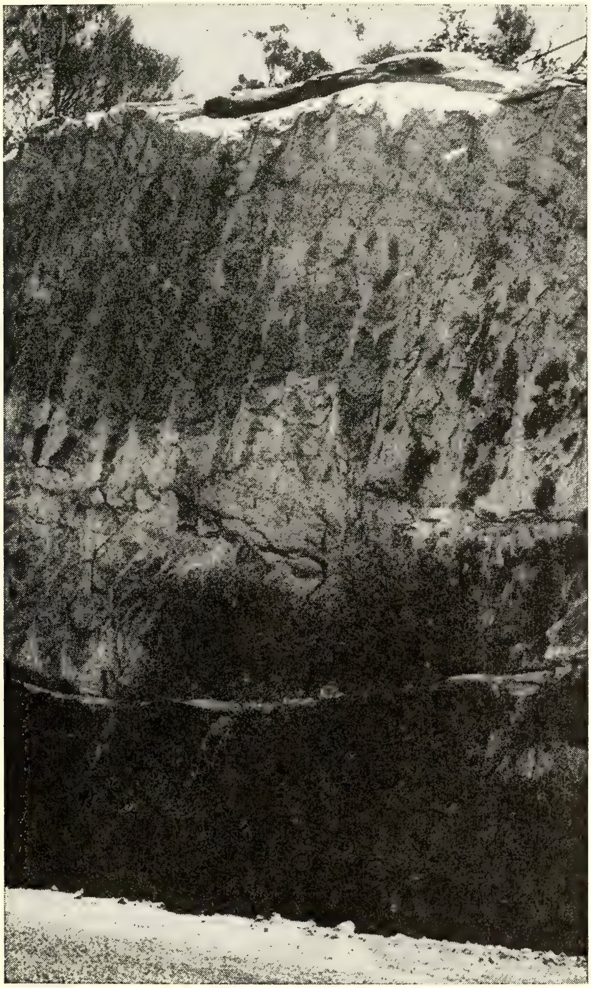

FIG. 3—Sandstone channel exposed in road cutting. The tesselated platform forms the upper surface of this sandstone. [*Note*—The drill marks formed during road construction should not be mistaken for columns.] There is evidence of considerable migration of iron through the channel sandstone.

the channel centre. One area, where the sandstone has been contorted by slumping, shows no patterned jointing.

The apparent restriction of the unusual jointing pattern to the channel sandstone east of the road suggests that the base of the channel may have been the locus of a sill-like intrusion, possibly related to nearby dykes. Heat escape could have been largely upwards, causing recrystallization of the overlying sandstone. The heavy iron-staining in the underlying sandstone may have been derived through chemical weathering of igneous rock, as is typical around the North Bondi intrusions. However, the clay seam underlying the channel sand contains quartz grains and mica flakes, indicating a sedimentary origin.

West of the road similar patterns, less well-developed, occur in a sandstone bed stratigraphically below the ferruginous sandstone unit. There are both vertical and horizontal columns which cannot be easily related to a possible heat source. The similar jointed sandstone at locality 3 has no obvious source of alteration but is close to several strong lineaments (Fig. 1). A small irregular neck-shaped body could be present in the valley between localities 1 and 3 but no breccia outcrops have been observed. Similar areas yet to be studied have been noted further north along the West Head road.

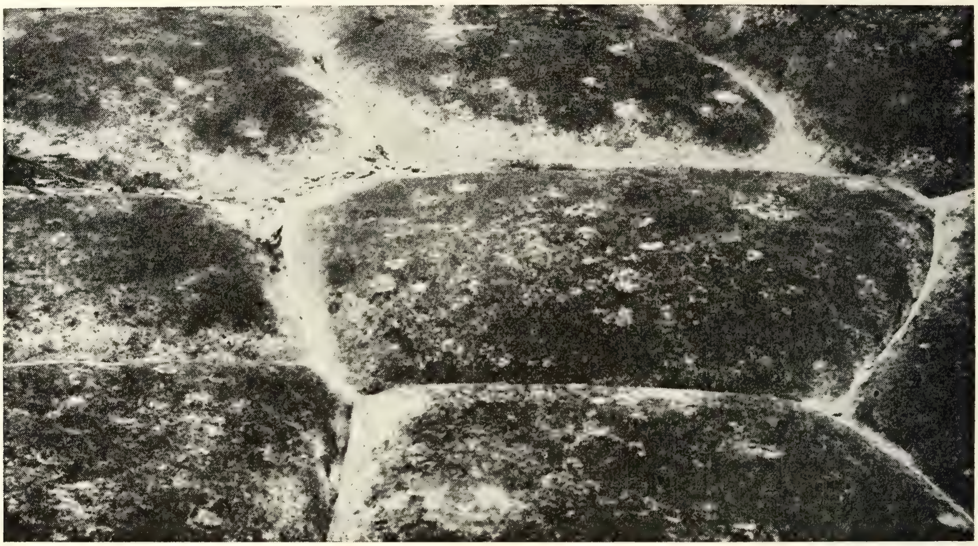

FIG. 4—Typical pattern near the south-west edge of the platform. Width of the polygons varies between 1 ft. 6 in. and 3 ft. in this area.

Conclusions

There is no clear evidence of contact metamorphism of the sandstone at the various localities examined, but such metamorphism is postulated despite the apparent lack of vertical penetration of the patterns. Spry and Solomon (1964) have dealt in detail with the possible causes of buchite formation adjacent to a basaltic intrusion and have pointed out the similarity of their altered sandstones to those of the Sydney district. The absence of evidence of such metamorphism is one of the characteristics of the area herein described, and an origin somewhat akin to mud crack development cannot be rejected at this stage. The changes involved in development of such phenomena are a neglected phase of geology which deserve attention. A detailed survey is proposed so that the specific relations between column shapes and sedimentary properties can be studied. Mr. Erskine, Chief Ranger of the Ku-ring-gai Chase National Park, believes there are other similar areas within the park and is compiling a list of localities which will also be studied. It is fortunate that this interesting exposure lies within the National Park and is being preserved; the road to West Head was, in fact, diverted for this reason. It is a park feature well worth a visit by geologists, but care is needed to preserve the surface from excessive wear.

FIG. 5—Typical pattern at the northern end of the platform. The well-defined elongate " columns " of Figure 2 become longer and less evident towards the north. The circular depressions common on the platform may have been artificially worn by aborigines as the sandstone is soft, especially in the centres of some of the equi-dimensional " columns ". There are numerous large carvings on the platform.

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A Note on Convex Distributions

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It is known that a convex function $f(x)$ defined and locally bounded on the real line is necessarily continuous (Rudin, 1966, Th. 3.2, p. 60 ; Boas, 1960, p. 142 *et seq.*). Also, if a convex $f(x)$ possesses a second derivative, then $f^{(2)}(x) \geqslant 0$.

If, instead of functions, we considered distributions, there are (at least) three possible definitions of convexity which reduce to the ordinary definition when the distribution is a function. These are :

(*a*) $T^{(2)} \geqslant 0$, which has a meaning since distributions are infinitely differentiable ;

(*b*) $T(x+h)+T(x-h)-2T(x) \geqslant 0$ for all h, which has a meaning if the distribution is defined over D ;

(*c*) $T(x_0+h_0)+T(x_0-h_0)-2T(x_0\text{-}) \geqslant 0$ for all x_0 and h_0,

where $T(x_0+h_0)$, $T(x_0-h_0)$ and $T(x_0)$ signify the values of T taken in the sense of Lojasiewicz (1957) at the points x_0+h_0, x_0-h_0 and x_0 respectively.

(In definitions (*a*) and (*b*) we understand $T \geqslant 0$ to mean $\langle T, \varphi \rangle \geqslant 0$ for all φ in D such that $\varphi(x) \geqslant 0$ for all x.

Considering first (*a*), we note that $\langle T^{(2)}, \varphi \rangle \geqslant 0$ for all positive φ in D implies that for all φ in D

$$\langle T^{(2)}, \varphi \rangle = \int \varphi(x) d\mu(x)$$

where μ is a positive measure on the Borel sets on the real line (Gelfand and Vilenkin, 1964, Th. 1, p. 142).

Since μ is positive, we may write $\int \varphi(x) d\mu(x)$ in the Stieltjes form $\int \varphi(x) dv(x)$, where

$$v(x) = \int_{[a,x]} d\mu.$$

Here we take a to be any real number less than the support of φ and $[a,x]$ to be closed. Then $v(x)$ is an increasing positive function.

Now

$$\begin{aligned} \langle T, \varphi^{(2)} \rangle &= \langle T^{(2)}, \varphi \rangle \\ &= \int_{-\infty}^{\infty} \varphi(x) dv(x) \\ &= \int_{-\infty}^{\infty} \varphi^{(2)}(x) dx \int_0^x v(q) dq \end{aligned}$$

(using integration by parts).

Thus in a distributional sense

$$T^{(2)} = S^{(2)}$$

where

$$S = \int_0^x v(q) dq$$

is a continuous function. From which we see that

$$T = S + ax + b \quad (a,\ b \text{ constants})$$

(Friedman, 1963, p. 56).

We do not know whether $S^{(2)}$ exists as an ordinary derivative or not. However, it is easy to see that

$$S(x+h)+S(x-h)-2S(x)=\int_x^{x+h} v(q)\mathrm{d}q-\int_{x-h}^{x} v(q)\mathrm{d}q\geqslant 0.$$

Thus S and T are distributions generated by continuous convex functions.

Now suppose that $\varphi\geqslant 0$ is in D. Then

$$\langle T^{(2)},\varphi\rangle=\lim_{h\to 0} h^{-2}\langle(T(x+h)+T(x-h)-2T(x)),\varphi(x)\rangle.$$

If (b) holds, then the right side of this equality $\geqslant 0$. Thus $T^{(2)}\geqslant 0$, and (b) implies (a).

The value $T(x_0)$ of a distribution T at a point x_0 is defined by Lojasiewicz as follows: Suppose that

$$\lim_{\lambda\to 0}\langle T(x_0+\lambda x),\varphi(x)\rangle=\langle C,\varphi(x)\rangle$$

for all φ in D, and that C is a constant distribution. Then

$$T(x_0)=C.$$

We assume that $T(x_0)$ exists for every x_0. Then Lojasiewicz (1957), Th. 5.7 shows that $T(x_0)$ considered as a function of x_0 is a Baire function of class 1 and is thus measurable. Corollary of section 5.2 of the same reference proves that if $T(x_0)=f(x_0)$, then $T(x)=f(x)$ in the distributional sense. So if we assume that

$$f(x+h)+f(x-h)-2f(x)\geqslant 0$$

then

$$T(x+h)+T(x-h)-2T(x)\geqslant 0$$

in the distributional sense, which is the assumption in (b).

Thus in case (c) $T(x)$ again is equal to a continuous convex function.

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Geological Techniques*

ALAN H. VOISEY

ABSTRACT—Geological techniques are demonstrated by an approach towards the history of the growth of land masses from an original basaltic crust of the earth. The gradual formation of complex continents through the sub-areal decomposition of basalts and subsequent tectonism is proposed. Successive stages in development are illustrated by types of land mass existing at present, e.g. oceanic islands, and those in island arcs. The suggestion is made that vulcanism and tectonism are essential to the maintenance of life on earth through the supply of unstable rocks which provide new soil and energy through their breakdown under surface conditions.

The word used for descriptive work on the earth's materials in the 18th century was " geognosy ". This study was defined by Abraham Gottlob Werner as the " Science which inquires into the constitution of the terrestrial body, the disposition of fossils (meaning both minerals and petrified organisms) in the different rock layers and the correlation of the minerals one to another ".

Today some people are still inclined to accept this as the definition of geology.

Under the name " geology " suggested by De Luc, Werner would only recognise speculations about the origin and history of the earth but it was James Hutton who gave modern geology its start in his paper on the " Theory of the Earth ", read before the Royal Society of Edinburgh in 1785. Hutton here presented his ideas on the origin of rocks, the development of the earth's crust and the pre-existence of older continents and islands from which the more recent land areas must have been derived. He likewise discussed the evidence for the previous existence of faunas and floras from which present types of life must have sprung. Hutton understood more clearly than his predecessors a number of phenomena such as the slow processes of subaerial denudation and deposition. He consequently introduced ways of thinking which do not appear to have been exploited by them. As Zittel (1901, p. 71) pointed out, the great feature which distinguished Hutton's theory and marked its superiority was the strict inductive method applied throughout. Every conclusion was based on observed data that were carefully enumerated. No supernatural or unknown forces were resorted to. Events and changes in past epochs were explained by analogy with the phenomena of the present age.

Geology as envisaged by Hutton is really Earth History and consequently is related to our concept of time. Events follow one another in sequence. Each is related to its predecessor and its successor. Parts of a sequence are related as cause and effect. In the context of the availability of long periods of time it is usually difficult to find a beginning and even more difficult to foresee an end. It is possible to recognise a process slowing down or accelerating. Extrapolation of observations in either direction has to be done cautiously. Data can be plotted just as if experiments had been carried out.

Geological techniques therefore, involve both space and time without necessarily having recognisable limits. To illustrate this point let us consider a granite decomposing to a soil. The granite exposed at the earth's surface breaks down slowly to a soil made up of quartz grains, clay, limonite and organic matter. The products of breakdown become stable as a result of the chemical and physical conditions existing on the earth's surface at that place and over a certain period of time. The granite had been stable under conditions deep in the earth's crust where it was formed, probably through melting of rock materials which themselves had an earlier history. It was not stable near the surface.

The geologist does not have to devise an experiment to show how the mineral feldspar in a granite breaks down to form clay. Indeed, the process takes a long time and cannot be conveniently carried out in a laboratory. The observation of the stages of breakdown from granite to soil gives a more complete picture of the nature of the chemical change than is

* Presidential Address delivered before the Royal Society of New South Wales, 5 April 1967.

usual in an experiment of similar type because the intermediate products all exist at the same time.

Sir Charles Lyell's " Principles of Geology " was described by him as " an enquiry how far the former changes of the earth's surface are referable to causes now in operation ". The uniformitarian doctrine developed by Lyell is just one application of our belief in the continuity of natural processes and in the operation of the laws of physics and chemistry which have been formulated and on which progress in our knowledge of science depends.

which the layered rocks were deposited and his his correlation of them by means of the contained fossils led to the formulation of " the law of super-position " and provided the means of determining the sequences of events in the history of the earth. It is of interest to note that biologists have been able to confirm some of the findings of geologists by similar techniques—e.g. observing stages in the growth of some organisms. In their development these forms pass through adult stages of their ancestors—" the ontogeny recapitulates the phylogeny ".

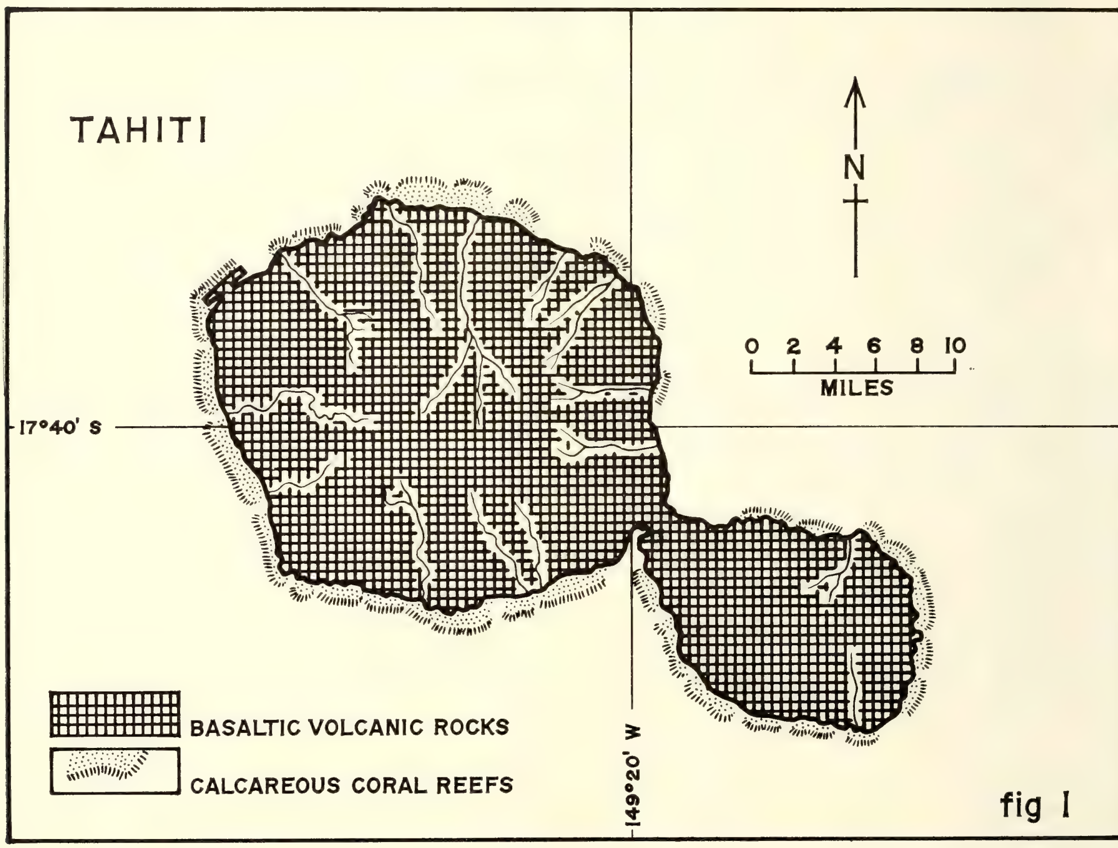

Fig. 1—Tahiti.

Collection and selection of the data to be used in the attempt to work out a particular problem, and not infrequently its preparation for study, occupy most of a geologist's working time.

William Smith, an English engineer, carried out field observations over many years and was able to produce a geological map of England and Wales from his knowledge of the distribution of the rocks. His recognition of the order in

Dr. M. K. Hubbert (1963, p. 375), in his Presidential Adress to the Geological Society of America pointed out that " the evolution of science is, in fact, not a progression from the simple to the complex—but quite the opposite. It is a progression from the complex to the simple ".

In geognosy the initial collections included a wide variety of forms. Geologists in making

their observations had to contend with a chaos of land-forms, configurations of land and water and so on. From this great mass of material they have managed to decipher much of the history of the earth.

Many geological techniques for dealing with selected data are not now peculiar to the subject but are the same as those of the other sciences, even to the extent of mathematical representation and interpretation. The real differences between geology and other disciplines lies not in the methods used but in the problems which each attempts to solve.

The history of the land masses which now rise above the oceans constitutes perhaps the most important geological problem which may be approached by the application of what may be called geological techniques.

By noting processes going on at the present time on the earth's surface and by considering those known to have taken place in the not too distant past it is possible to recognise orderly sequences of events leading to the formation of the various rock types which make up the land.

By reversing this sequence and observing the combinations of rocks, geological structures and land-forms we can extrapolate backwards in time. The complex continents may be dissected and a series of stages each more simple than the previous one may be recognised, with a simple volcanic island seen as possibly the earliest land-mass.

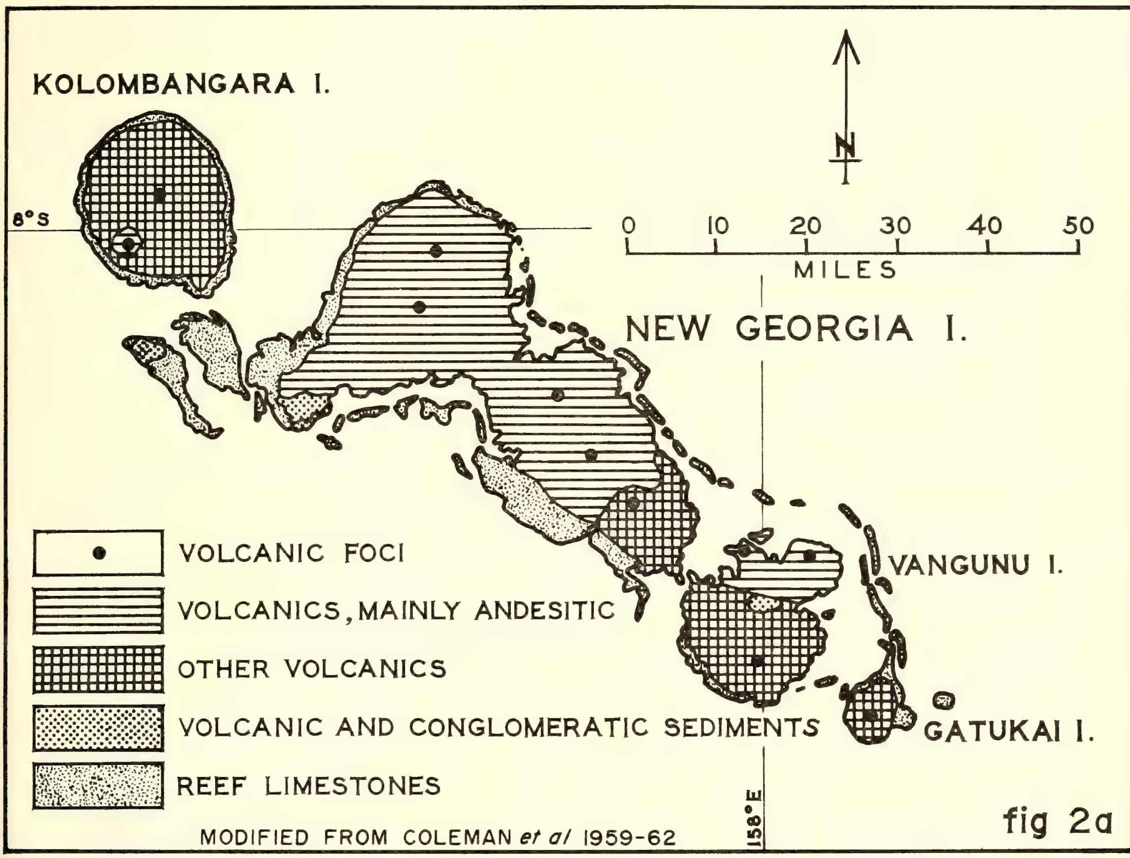

Fig. 2*a*—New Georgia, Solomon Islands.

Analogous stages in continental development may be selected from existing islands today. A small number of these sufficient to illustrate the technique have been chosen and are shown in figures 1, 2*a*, 2*b*, 3, 4, 5, 6. The continents themselves have not been included but they are known to be made up of older Pre-cambrian nuclei with fringing and overlying Phanerozoic and younger rocks.

Oceanic Islands

Let us now proceed in time to develop a complex land mass from what is assumed to have been an earth with a basaltic surface layer overlying a mantle of ultramafic character. A greater mobility than that shown by the earth's crust today is probable with many volcanic eruptions taking place.

When exposed above the primeval ocean basalt in an atmosphere containing gases similar to those existing today (but certainly in different proportions) would break down to form clays, iron oxides and hydroxides together with some silica. The soluble calcium, sodium and potassium and magnesium salts formed would move down the streams into the ocean. In some places pebbles and sands of undecomposed basalt would temporarily accumulate in valleys and along the margins of the land as beaches. Before the advent of life there would be little or no extraction of calcium carbonate from the sea water but later algal reefs would have developed. From Silurian time onwards corals and other organisms shared in the building of fringing reefs and banks. Calcareous sands and muds and siliceous cherts fringed the islands mantling the ocean floor. Note the island of Tahiti consisting of two basaltic cones (Figure 1) which illustrates this early and simple stage in growth. Oceanic islands of similar character have existed since earliest times.

All the products of sea-floor eruptions do not reach the surface but form sea-mounts and various land forms beneath it.

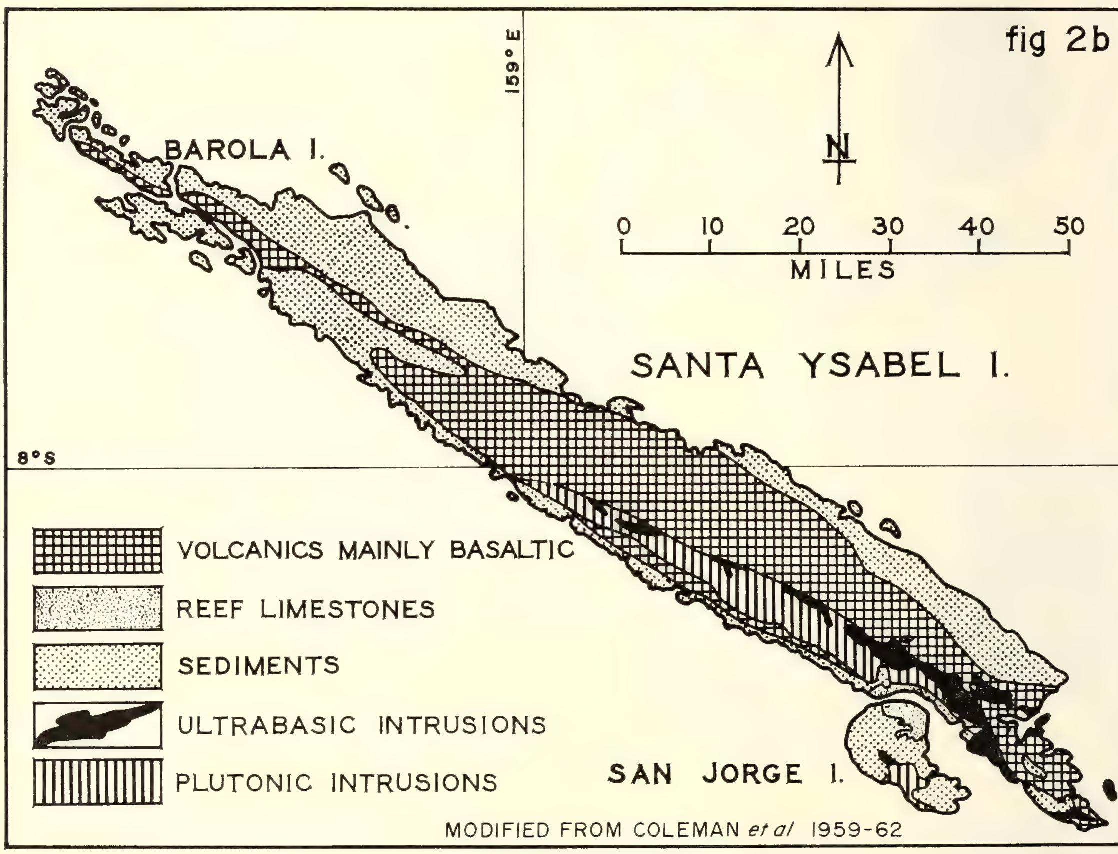

Fig. 2b—Santa Ysabel, Solomon Islands.

Island Arcs

While certain parts of the earth's crust appear to be relatively stable, or to move upwards or downwards in great swells or sags, there are some broad zones where there is much more movement. These mobile belts are at present localised in two intersecting great circles—one approximating to the boundaries of the Pacific Ocean and the other cutting approximately through the Afro-Asian land-

mass to the Mediterranean Sea. Within these and similar belts in the past the products of volcanic activity and erosion have been drawn down into the crust, sometimes to depths of up to ten miles. Geophysicists have been able to produce evidence of much of the structure of such belts, which are distinguished by negative Bouguer anomalies. Temperatures and pressure conditions at these great depths are very different from those at the surface. Combinations of the elements change and new minerals stable under these conditions, are formed.

Geochemists have been working with artificial melts in an attempt to understand the processes going on and the reasons why particular minerals are formed. In both the above cases, geologists apply their techniques or methods of reasoning to the problem. Minerals actually found on

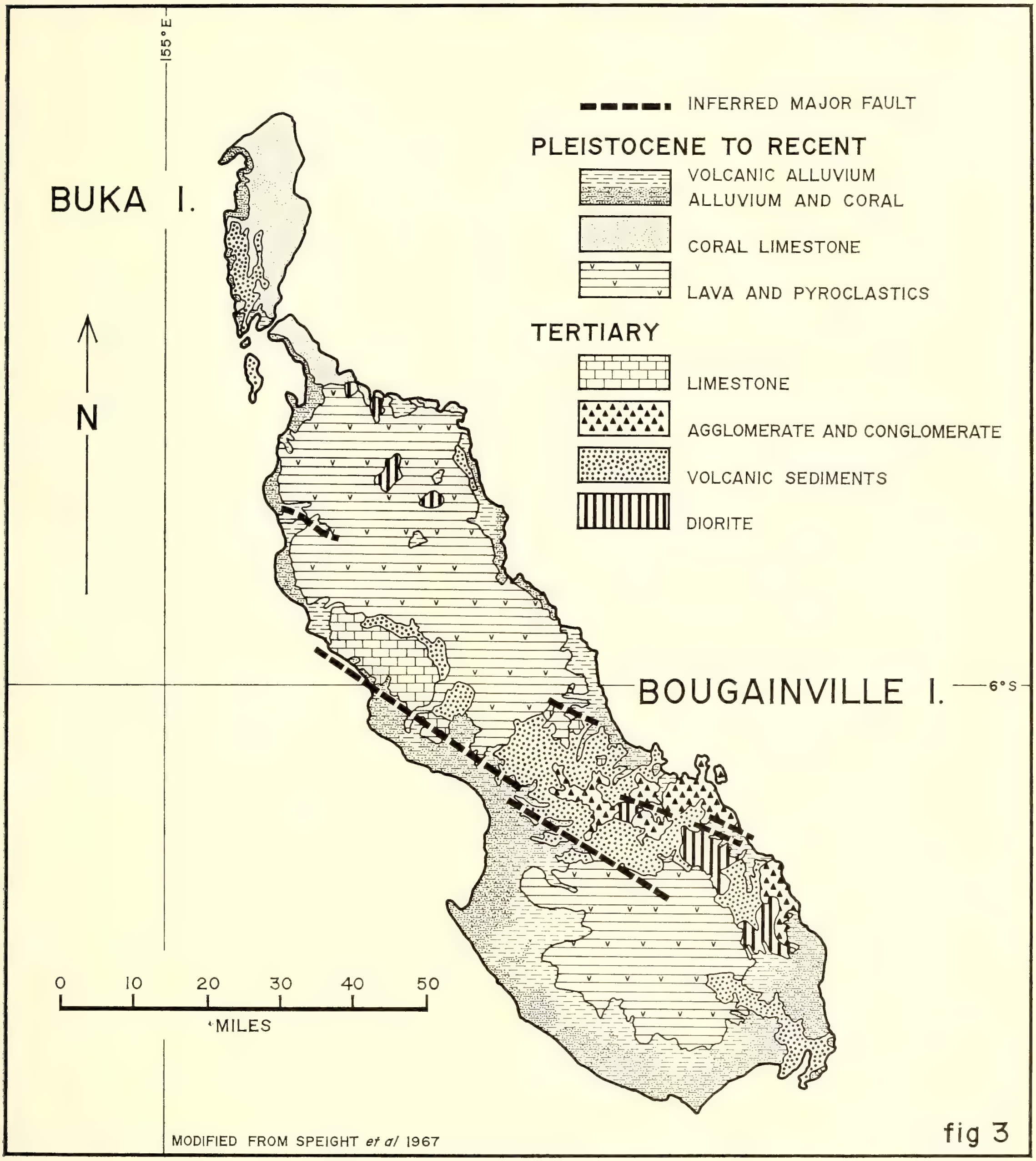

Fig. 3—Bougainville, Solomon Islands.

the surface are compared with those produced artificially. The difficulties in using the information obtained with only some of the products actually available, are quite great. Liquids or gases present at the time of formation are not necessarily still available but it is recognised that their presence or absence has had an influence on what mineral was in fact formed.

Typical volcanic rocks developed in the mobile belts are andesites but with them are basalts, trachytes, dacites and rhyolites. We have here another problem in geochemistry, but a number of petrologists believe that these rocks are derived from a basaltic magma which has had various quantities of erosion products mixed with it. Variations in the volcanic rock

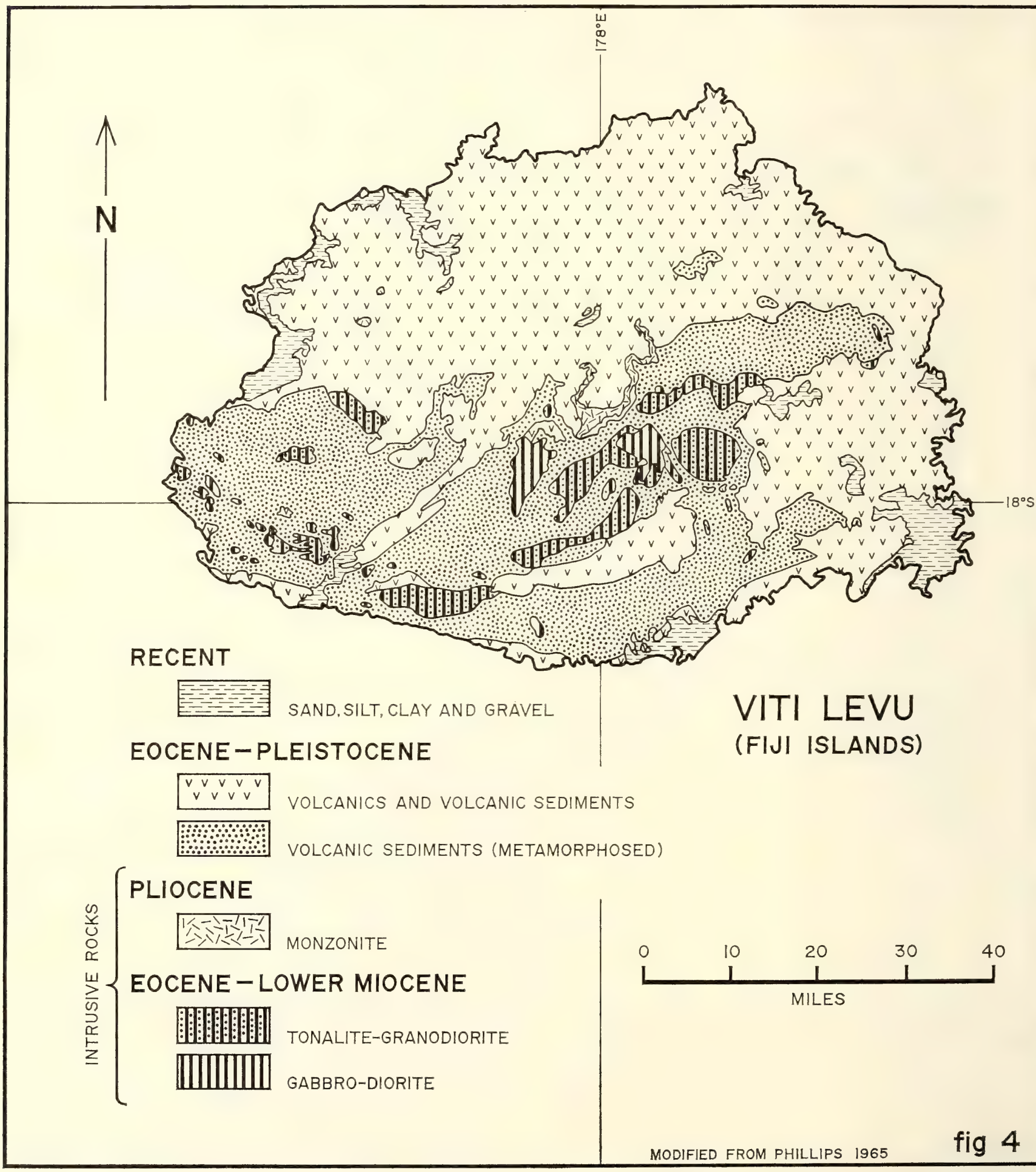

Fig. 4—Viti Levu, Fiji Islands.

types and their proportions would be expected under these circumstances.

Within the Solomon Island group (which lie in the eastern Pacific mobile belt) there are a number of different evolutionary stages existing today. New Georgia (Figure 2*a*) and Santa Ysabel (Figure 2*b*) are typical early developments. There are few rock types besides the lavas and their breakdown products. The presence of ultra-basic rocks on Santa Ysabel is evidence of the squeezing upwards of the rocks of the mantle. Such rocks have long been recognised as being characteristic of island arcs.

It would appear that explosive andesitic eruptions have produced enormous quantities of pyroclastic material. It may well be that

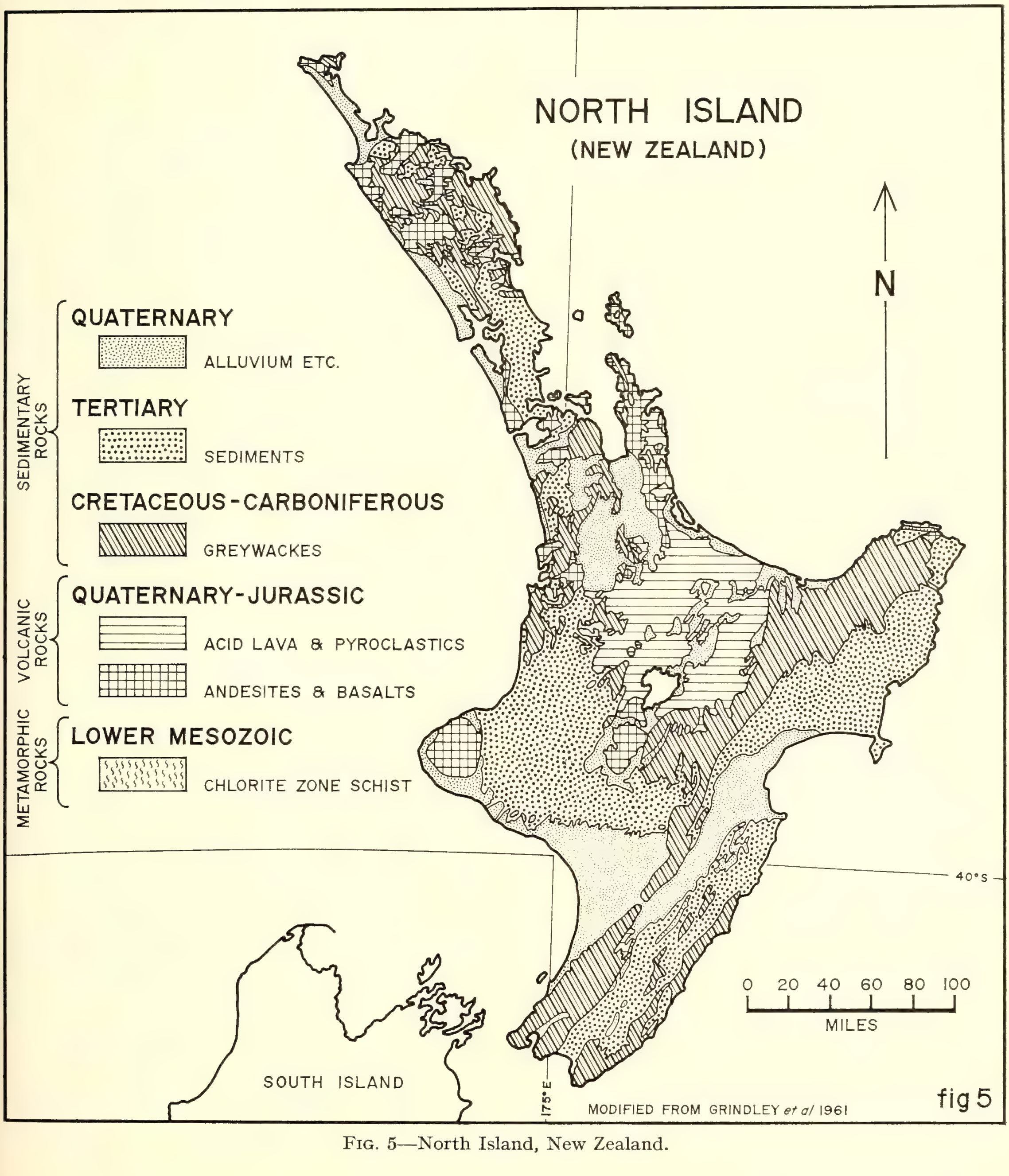

FIG. 5—North Island, New Zealand.

in eugeosynclines this forms the major content. Most of it probably settled into the sea or was immediately washed there by the streams. Jacobs, Russell and Wilson (1959, p. 77) recognised the importance of andesitic vulcanism in continental growth and quoted analyses to show how closely the average composition of the continental crust corresponded with the compositions of andesites, greywackes and granodiorites. They suggested that " all are so similar that it is easy to believe that the continents have been built up from lava of the andesitic kindred, eroded to greywackes and recrystallised to plutonic granodiorite gneisses.

The island of Bougainville (Figure 3) includes among its lavas and pyroclastic deposits plutons

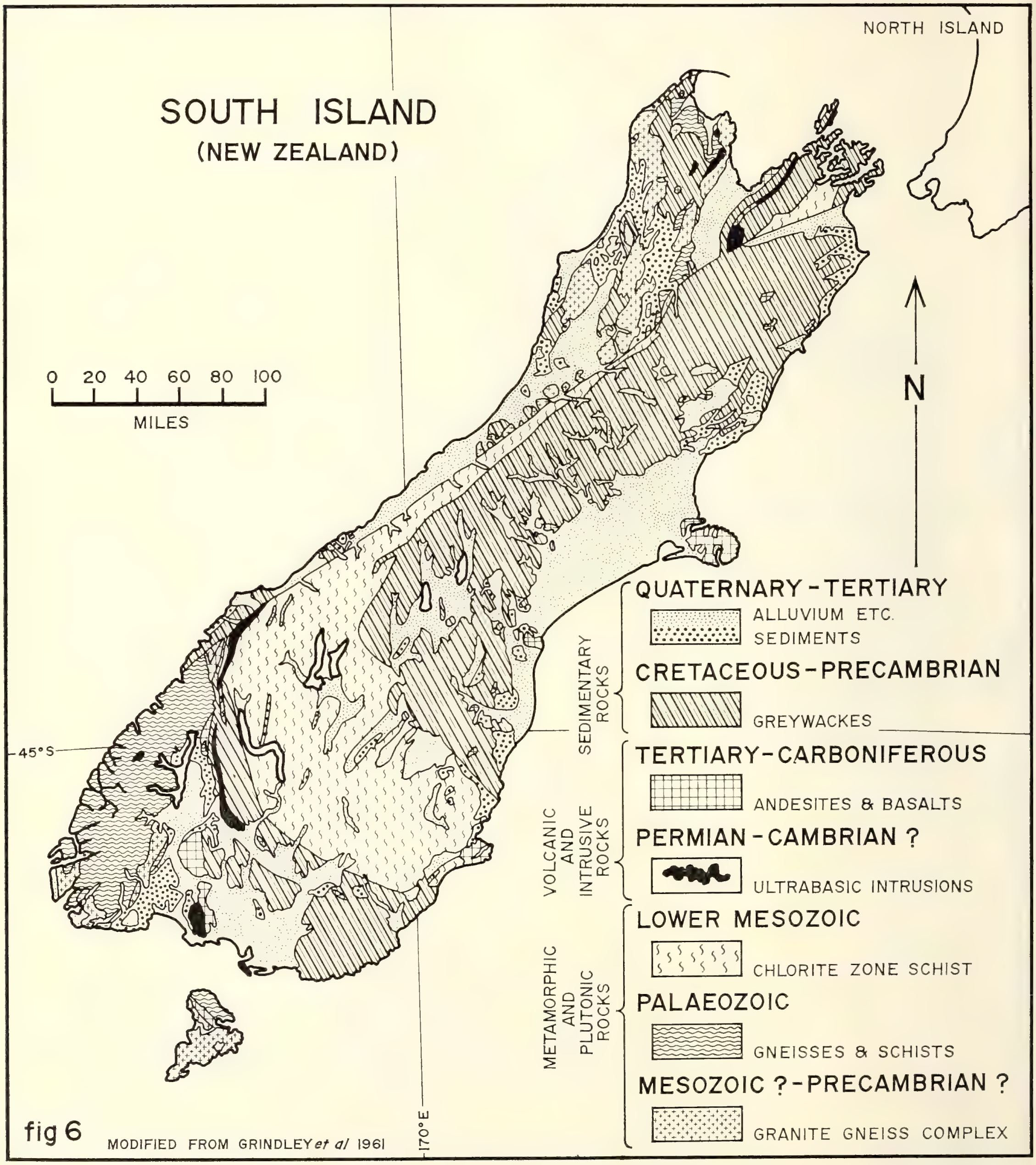

Fig. 6—South Island, New Zealand.

of diorite presumably derived through the melting of these at depth. The increasing variety of rock types in the evolutionary sequence is apparent and the relationship of one to the other clearly recognised.

Viti Levu in the Fijian island group (Figure 4) has a still greater number of rock-types including monzonite, tonalite-granodiorite and gabbro-diorite. Exposure of these indicates more uplift from the position in the crust where such reorganisation of materials was possible to a height above sea level which allowed a great deal of erosion to occur and thus expose the plutons.

Until coarsely crystalline igneous rocks become eroded there does not appear to be any substantial source of quartz grains. Consequently quartz sand and quartz sandstones are relatively rare on islands. It is of some interest to compare the sands fringing different kinds of land mass. Those on oceanic islands are of basalt or calcareous debris derived from the shell beds or reefs. Olivine sand is known from some. Larger islands such as Viti Levu have some quartz and rock fragments together with the calcareous grains. On the other hand, the sands of the beaches fringing the Australian continent are of the end-product type—quartz, magnetite, ilmenite, rutile, zircon and some heavy minerals.

The larger islands which apparently developed in the mobile belts possess increased diversity of rocks and structures. The two main islands of New Zealand (Figures 5 and 6) contain between them rocks ranging from early Palaeozoic even possibly Precambrian to Recent and from metamorphic and plutonic igneous types to Recent falls of volanic ash. The South Island possesses the features of a small continent and indeed has even been thought to have once been part of the Australian block. Its complexity is such that it could be regarded as a near final stage in the development of land in a mobile belt.

Investigation of the land masses indicates that all have originated from orogenic belts whose former presence and position are recognised from a study of the rock types. It should be possible to trace the former position of the mobile belts and crustal weaknesses.

Continents

The manner of growth of the continents has been discussed over the years. They were originally thought to have been portions of a primordial crust, then to have formed by growth round the margins. Recognition of the types of geosynclines which contribute to continental growth has brought together the ideas of mobile belts, island arcs and marginal accretion. Several theories have placed the major geosynclines in causal relationship with the land masses themselves. It is difficult, however, to relate the present-day mobile belts to the continents. One cannot help putting forward the possible alternative view that they are independent of them and related to more fundamental weaknesses in the earth. Note how they margin the Americas, join them up, then cross to Antarctica and continue to New Zealand, the Solomon Islands, the Philippines and Japan.

If the present belts are not related to the land masses, where were those of the past ? Some at least were parallel—e.g. the Rocky Mountains Geosyncline, the Tasman Geosyncline and the Hercynian Geosyncline.

The openings in the ocean floors up which basalts have been moving form yet another fracture pattern, which may well be related to the mobile zones perhaps through convection currents in the earth's mantle. On the other hand these may be the beginnings of the more complex mobile belts and may develop into them. An alternative suggestion is that the earth's crust is progressively becoming more stable with consequent changes in the character of fractures.

Whatever their relationships it would appear that most significant contributions to the land masses have been related in some way to belts of andesitic vulcanism since the beginning of the Palaeozoic time.

It would probably be possible to work out quantitatively the disposition of the products of erosion of the orogenic belts thus formed during the last 500,000,000 years. Most of the sediment would have been trapped in adjacent depressions and not distributed over the ocean floors.

To account for the materials composing the continental shields or nuclei requires another pattern of crustal fractures. Analysis of these Precambrian areas has shown them to be made up of sediments and igneous rocks arranged in comparable fashion to those in the more recent mobile belts and showing somewhat similar compositional constitutions. Presumably the older belts have " healed " and we will need much more data in order to make comparable interpretations to those put forward here for the more recently formed land.

There seem to be sound reasons for belief in the development of land masses as "scabs" on the earth, related to chemical processes within and on the crust. Without the atmosphere there could not have been much variation in rock type even with crustal mobility unless deep seated material moved upward.

This interpretation supports the view that the surface rocks of the moon should be all of the same type, except for additional meteoric material. They could well be basalt.

The idea of evolution of the crustal rocks leads to some interesting speculations as to the future of the earth's surface. Since the discovery of radio-active minerals and the recognition of their contribution to the internal heat of the earth, the view that the earth was a cooling—and consequently a shrinking—body, has been modified. Nevertheless, there seems to be the possibility that the crust was more mobile in early Precambian times.

The growth of continental nuclei from Cambrian times onwards can be recognised and described in some detail.

Although strong arguments in favour of continental movement continue to be advanced, the orogenic belts do not appear to have moved very much from their present positions during the last 500,000,000 years. The increase in land areas seems to have followed the filling and consolidation of parts of these broad belts.

Former orogenic belts have been recognised within the continental shields and it would appear that the rocks constituting them have originated in much the same manner as those of their Phanerozoic margins. The sequence of growth has yet to be determined in detail, but if the stable land masses originated in the manner described, they may have been progressively smaller, going back in time. On the other hand they may have been associated with larger areas of a more or less primordial basaltic crust in the early days, 3,000,000,000 years ago.

Looking to the future, if there is progressive stability, there should be decreasing vulcanism and decreasing diastrophism. Freedom from earth movements must lead to peneplanation, and perhaps the development of stable materials such as the laterite, which formed over Australia during a long period in Tertiary times. Leaching of the surface rocks and the formation of end products of rock breakdown could be expected to occur over all land areas. Vegetation would tend to deteriorate and consequently associated animal life, including man.

The alluvial plains and volcanic areas of the crust are the main habitat of man and in both areas we have chemical instability and continuous change. No additions of alluvium and no additions of lava mean no new soil and no new growth.

As life on earth is generally believed to be due to solar energy it is an interesting thought that earth movements and vulcanism are also involved and form a very necessary condition for life. Their possible absence from other planets may be due to the fact that internal movements had ceased and the crust had stabilised.

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The Geology of the Narooma Area, N.S.W.

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Abstract.—A succession of slates (Bogolo Formation), cherts and altered basic volcanics (Wagonga Formation), and a sequence of undifferentiated greywackes outline a major anticline at Narooma on the far south coast of New South Wales. The Bogolo and Wagonga Formations are new formations, being subdivisions of an Undifferentiated Ordovician Sequence. No evidence for an unconformity between the Bogolo-Wagonga Formation, and the overlying greywackes has been found in the area which would justify the assigning of a Cambrian age (Brown, 1933) to the former formation.

Igneous activity in the area includes Devonian (?) acid and basic dykes, with a small Devonian (?) outlier of basaltic lava, Permian (?) trachytic dykes, two Cretaceous monzonitic satellites of the Mount Dromedary Complex. A number of lamprophyric dykes also intrude the sequence.

Introduction

A sequence of strongly folded Ordovician greywackes, containing a large fold defined by cherts, basic volcanics, slates and arenites is found at Narooma on the south coast of New South Wales (Figure 1). Upper Devonian rocks unconformably overlie these deformed rocks and are extensively developed to the west of the area. North of the area, there is a satellite of Moruya granite and to the south the Cretaceous monzonite complex of Mount Dromedary. Extensive Tertiary sand and gravel deposits are found throughout the region together with isolated cappings of Tertiary basalt.

The first detailed geological investigation of the south coast of New South Wales was undertaken by Brown (1925, 1928, 1930, 1931, 1933), who described the distribution of the various rock types of the south coast stretching from Nowra to Eden.

Brown (1928, p. 154) considered that the pre-Devonian sedimentary sequence of the south coast may be divided into two series, the younger of the two being all the psammitic and pelitic rocks found west of Observation Point, Bateman's Bay. To these rocks she applied the name " Slate series ". The older series of rocks were the " crushed " conglomerates, quartzites, cherts and slates which typically outcrop at Observation Point and also in the Bodalla and Narooma areas.

In 1962, Hobbs referred to the chert and slate sequence and Ordovician greywackes collectively as the Wagonga Beds. On the other hand, it has been the custom of members of

Table 1

Relationship between the new and old nomenclature

Rock type present	I. A. Brown 1928–1930	W. R. Browne 1949–1950	N.S.W. Mines Dept. Geological Map 1962	Hobbs 1962	Herein	
Undifferentiated Greywacke and Pelite . .	Slate Series	Upper Ordovician	Ordovician		Undifferentiated Greywacke and Pelite	Undifferentiated Ordovician sequence
— ? — ? — ? — ? —						
Dark well bedded Chert, lavas, Volcanic breccia and tuff.	Older Series	Wagonga Series	Wagonga Beds	Wagonga Beds	Wagonga Formation	
Slate phyllites boulder beds arenites and some chert.					Bogolo Formation	

— ? — ? — Junction not specifically defined.

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the N.S.W. State Geological Survey to regard the upper limit of the Wagonga Beds to be the chert-greywacke boundary, this being apparently based on the assumption that the undifferentiated greywacke sequence overlies the cherts unconformably. No evidence for or against an unconformity has been seen in this area and it is the author's belief along with other workers (M. A. Etheridge, P. F. Williams, and R.G.Wiltshire, personal communication) that

In this paper, it is proposed to deal with the general geology of the area and to subdivide the undifferentiated sequence into two formations; a detailed description of the structure will be described elsewhere. Co-ordinates are given for field localities from the Bega Geological Sheet. The five figure numbers refer to specimens and sections in the collection of the Department of Geology and Geophysics, University of Sydney.

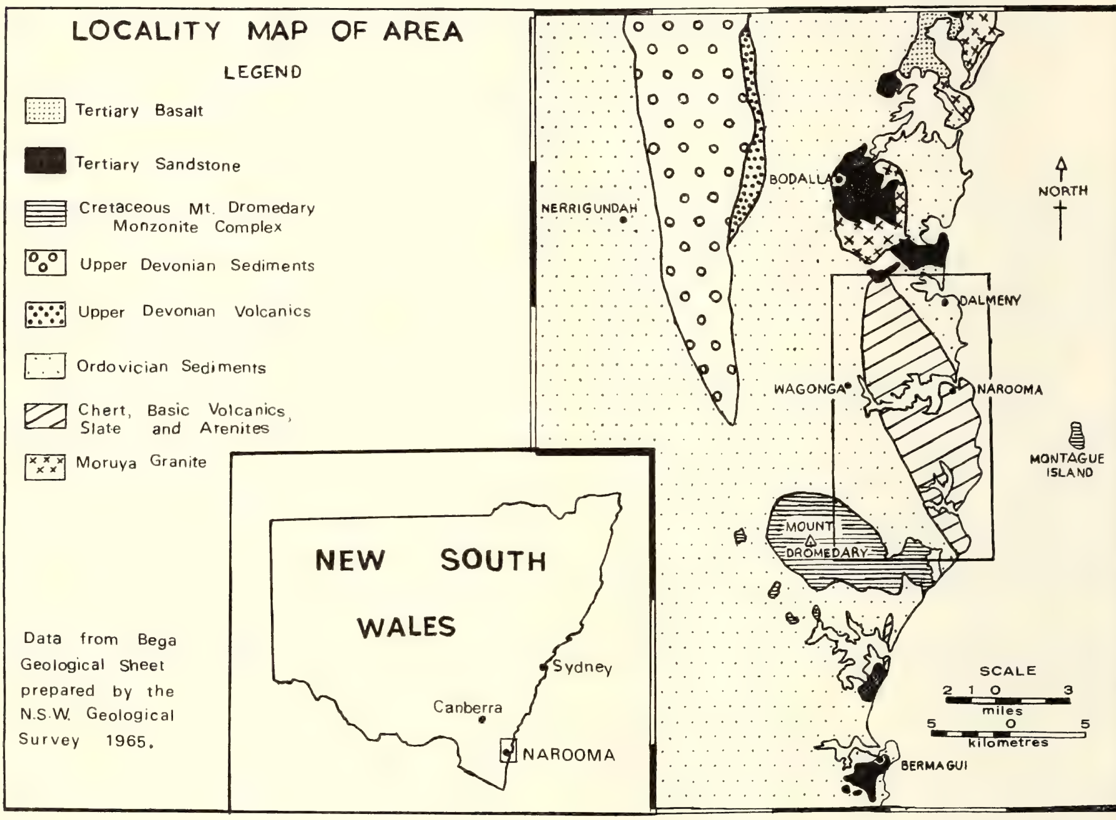


Fig. 1

to the north and south of the Narooma area the cherts and greywacke sequences are possibly conformable.

The above nomenclatural history for the name "Wagonga" is summarised in Table 1, and there appears to be no justification in assigning these rocks to the Cambrian. It is also evident that the name has been inadequately defined with its use in several different senses at different times even since the introduction of the Australian Code of Stratigraphic Nomenclature.

Stratigraphy

The stratigraphy of the sedimentary rocks in the Narooma area is summarised in Table 2. The pre-Tertiary sedimentary sequence has been intensely folded and it is not possible to measure the stratigraphic thicknesses of any formation with any degree of accuracy (c.f. Cloos, 1947).

The thicknesses given in Table 2 are those estimated in the present type sections. Outcrop of these older sedimentary rocks is generally very poor and the depth of weathering and

associated secondary alteration is as great as 800 ft. in most parts of the area. This is possibly because there has been a continuation of the pre-Tertiary, or even earlier, weathering.

TABLE 2

Age	Formation or Rock Type	Thickness
Quaternary ..	.. Sand, alluvium ..	Variable
Tertiary ..	.. Sandstone, gravels	20′ +
Undifferentiated Ordovician Sequence	Undifferentiated greywacke and pelite	3000′ +
	Wagonga Formation	1200′ +
	Bogolo Formation..	600′ +

BOGOLO FORMATION

The Bogolo Formation consists of slates and phyllites with subordinate boulder and arenite beds, and chert lenses (see Plate 1, Figure 1). It is extensively exposed along the shores of Corunna Lake and on the coast from the entrance of the Lake to the Glasshouse Rocks. The type sections lie between grid references 15902650 and 15772379 on the coast and between grid references 14002279 and 14002526 on the shores of the lake.

The slates and phyllites are moderately fissile and occasionally possess a strain slip cleavage. They vary in colour from light green to grey when fresh, and from yellow to light green to purple when weathered. They are generally fine-grained and are composed of white mica with subordinate pale green biotite and quartz. The quartz (up to 15%) occurs as fine-grained recrystallised aggregates or as detrital grains elongate in the plane of the foliation.

The arenites (in the sense of Pettijohn, 1957) are light grey or brown in colour, are generally discontinuous and are commonly found associated with " boulder beds ". They are usually 2 inches to 8 feet thick and are laminated due to variation in percentage of matrix material. The arenites have at least 80% detrital quartz, occurring mainly as angular and rounded grains of 0·3 to 0·6 mm. across. Feldspar (1%) also occurs in a white mica matrix, with occasional blades of a very pale green biotite.

The cherts of this formation are generally small lenticular, intensely folded bodies completely enclosed by slates and phyllites. These chert bodies are usually massive and similar to those described below in the Wagonga Formation, but may contain thin interbedded grey and red pelite layers alternating with layers of grey and black chert, no greater than 2 inches in thickness. The lenticular nature of the chert is believed to be a sedimentary feature rather than tectonic.

The name boulder bed was applied by Brown (1933) to the occasional layers of elongate " boulders " set in a slate, occurring at Bateman's Bay and Narooma. The " boulders " are generally arenites similar to those described above, and commonly have a shape approximating to a prolate ellipsoid with their major axes varying from less than 3 inches to 3 feet in length. The boulders are generally elongate in a direction parallel to the local fold axis and are strung out along the lithological layering as disconnected pods, although some are joined laterally to their adjacent boulder by a narrow neck, composed of the same material. Individual bedded units in association with the boulders, are either lenticular or consist of a series of dislocated blocks, which lie, and are commonly parallel to, a layering that has formed during folding. Many of these boulders are probably related to this deformation and are boudins (Lohest, 1909) formed in a series of interbedded pelites and arenites. On the other hand some boulders are deformed conglomerates.

THE WAGONGA FORMATION

The Wagonga Formation comprises a group of lenticular chert and volcanic units typically developed along the coastal section of Wagonga Head to the Glasshouse or Waramba Rocks, and in the vicinity of the Wagonga Trigonometrical Station. The type section locality may be found along the Wagonga River from grid reference 09002946 to grid reference 10472951. The two distinct lithological groups will be discussed separately as (1) the cherts and (2) the volcanic rocks.

(1) *The Cherts*

In the west of the area, two distinct lenticular chert layers have been distinguished. The easternmost layer adjacent to Corunna Lake consists of two main rock types: a hard massive black and grey bedded chert with beds varying from $\frac{1}{2}$ to 2 inches in thickness and a highly folded massive grey bedded chert, varying from $\frac{1}{8}$ to $\frac{1}{2}$ inch. Between adjacent chert beds are fine partings of a light grey or white pelitic material, which in most outcrops has been differentially removed by weathering.

The westernmost unit, which is narrow at Corunna Lake, thickens to the north of Ohlsen's Creek where it is the predominant rock type in the hinge of the major fold. The rocks

making up the southern section of this unit are composed of fine-grained siliceous beds varying in thickness from $\frac{1}{4}$ to 6 inches. Each bed consists of a dark compact chert base, gradually becoming lighter towards the top and terminating in a white or pale grey friable micaceous layer.

To the north of Ohlsen's Creek these pelitic cherts are only found to a limited extent. Much of the chert found in the hinge region is similar to that adjacent to Corunna Lake. Also interbedded with these cherts, are rare thin beds of red jasper and thin layers of carbonaceous slate.

The cherts on the eastern limb of the major anticline extend as far south as the Glasshouse Rocks. These also consist of the massive dark grey and black chert bands up to 20 feet thick together with the finer laminated cherts. Related to these are thin layered grey to white pelitic cherts similar to those found on the western margin, especially in the vicinity of the Wagonga Head.

The thin laminated grey to white pelitic chert consists of a mixture of secondary white mica and quartz. The laminations are defined by a series of white mica-rich layers, varying from 0·04 to 0·25 mm. in width, within which may be small veins and lenses of recrystallized quartz. The dark laminae are rich in limonite and often mask the white mica as in 31164.

The black cherts are generally unlaminated and are composed of carbon, fine recrystallized quartz and minor quantities of muscovite. Because of a metamorphosed condition, original microstructure in the rocks is often masked by recrystallization. Within the carbonaceous cherts small " windows " of clear recrystallized quartz are commonly found. These are either elliptical or spherical in shape and are believed to be the Radiolaria mentioned by W. R. Browne (In David, 1950). These structures consist of either spherical bodies with rims of fine recrystallized quartz and cores of carbon, or spheres of recrystallized quartz with boundaries gradational into the fine-grained chert matrix. There is no positive evidence that these small windows of quartz represent Radiolaria, for no signs of radiolarian or sponge spicules were observed. Alternatively these structures may be interpreted as small siliceous concretions.

The third group of cherts makes up the largest proportion of the sequence The rocks consist of very fine-grained aggregates (less than 0·1 mm. across) of recrystallized quartz and minor quantities of mica intersected by numerous discontinuous veins of quartz. It is considered that these rocks possibly represent recrystallized chalcedonic cherts.

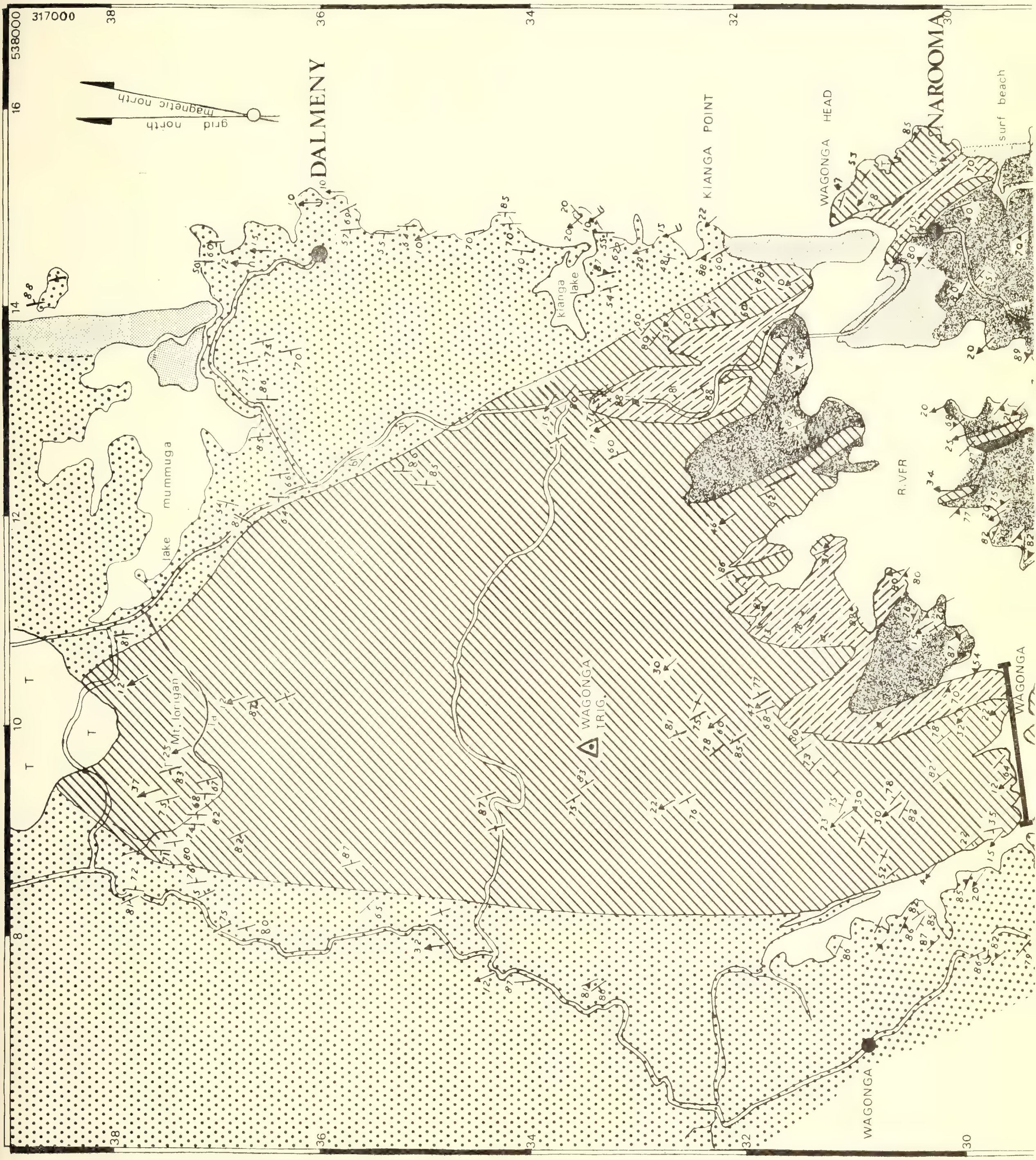
Quartz veins are ubiquitous, being developed throughout all the chert beds, especially within the more siliceous members. In most rocks at least two generations of quartz veins may be observed. They are frequently parallel to prominent superimposed structural surfaces such as an axial plane cleavage or may occur as numerous, irregular, intersecting, fine-grained, recrystallized quartz veins.

(2) *The Volcanic Rocks*

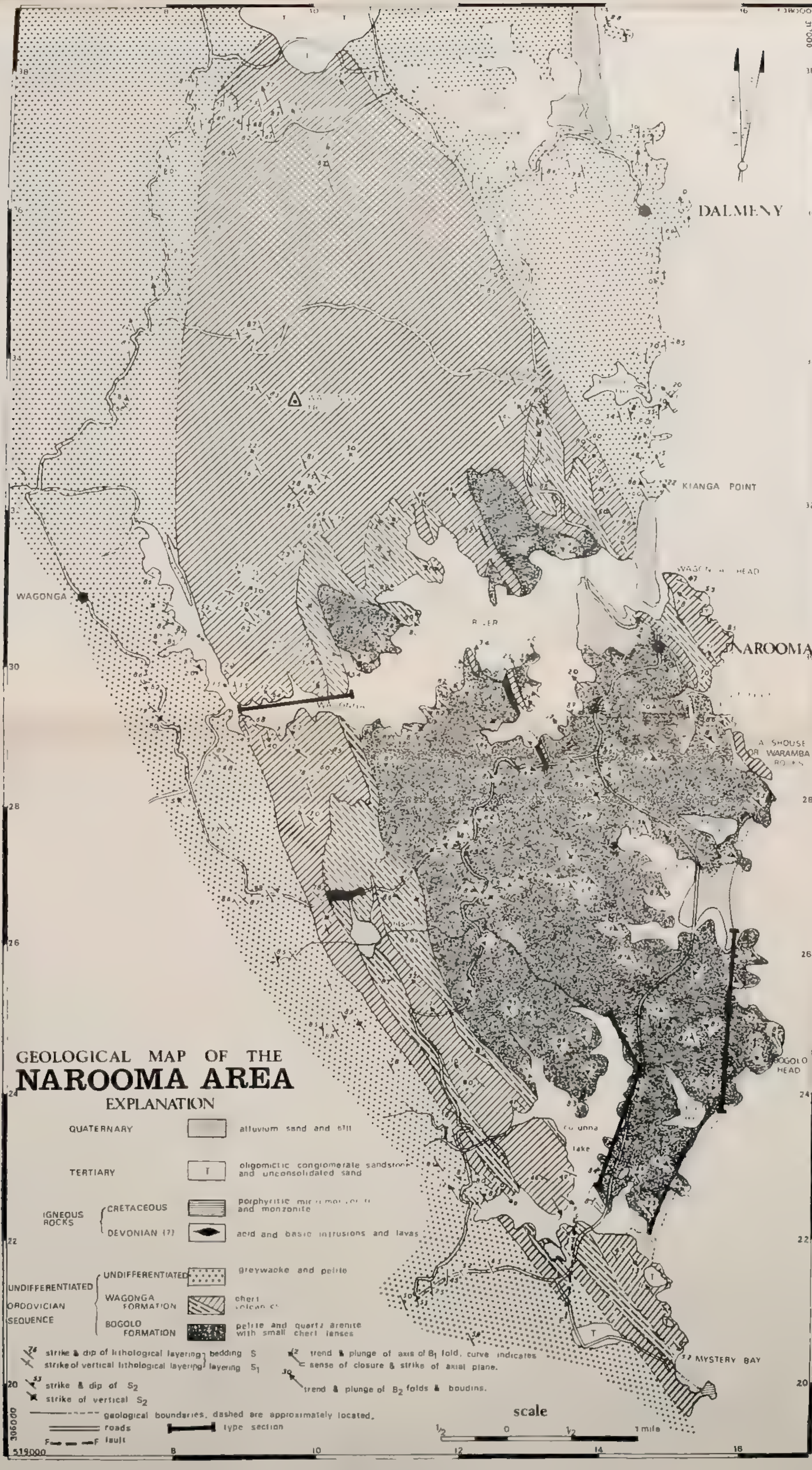
These consist of highly deformed lavas, breccias and tuffs, the outcrop of which, on the western limb of the Narooma fold, is characterised by two prominent layers separated by a chert lens. These two layers of volcanic material converge to the north of Ohlsen's Creek to form one unit which passes into the hinge of the fold where it becomes interbedded with finely layered cherts. In the east, a nearly continuous layer extends northwards from the Glasshouse Rocks to Kianga Lake. No pyroclastic rock or lava has been found adjacent to the underlying formation on the eastern limb of the fold.

Despite extensive regional metamorphism, it is possible to recognise three varieties of primary igneous rocks within the deformed volcanic sequence. These are massive igneous rocks, pyroclastics and pillow lavas. In the latter, the pillows occur as 3 inch to 3 foot elliptical bodies differentially weathered around their margins. Fresh specimens of individual pillows and associated margins can rarely be found on the coast or inland. Amygdales are present in most of the pillow lavas having either a spheroidal or tabular shape, and contain secondary fillings of chlorite, muscovite and calcite or alternations of all three minerals (30251), together with occasional quartz grains in irregular cavities of approximately 0·5 mm. to 2·8 mm. across. Below the layer of pillow lava at the north end of Surf Beach, there are a number of thin injections (approximately 2 inches wide) from the pillow lava into the underlying unconsolidated volcanic tuffs.

The lavas are either porphyritic or holocrystalline, the latter variety now consisting of equidimensional feldspar crystals set in a chlorite-rich mesostasis. The porphyritic lavas contain phenocrysts of albite (An_7), pseudomorphs after a more calcic plagioclase, and ferromagnesian minerals, set in a very fine mesostasis



DALMENY
NAROOMA
KIANGA POINT
WAGONGA HEAD
surf beach
kianga lake
lake mummuga
Mt. lorigan
WAGONGA TRIG.
WAGONGA
grid north
magnetic north


GEOLOGICAL MAP OF THE
NAROOMA AREA
EXPLANATION
QUATERNARY
alluvium sand and silt
TERTIARY
T
oligomictic conglomerate sandstone and unconsolidated sand
IGNEOUS ROCKS
CRETACEOUS
porphyritic and monzonite
DEVONIAN (?)
acid and basic intrusions and lavas
UNDIFFERENTIATED ORDOVICIAN SEQUENCE
UNDIFFERENTIATED
greywacke and pelite
WAGONGA FORMATION
chert
BOGOLO FORMATION
pelite and quartz arenite with small chert lenses
strike & dip of lithological layering
strike of vertical lithological layering
bedding S
layering S1
trend & plunge of axis of B1 fold, curve indicates sense of closure & strike of axial plane.
strike & dip of S2
strike of vertical S2
trend & plunge of B2 folds & boudins.
geological boundaries, dashed are approximately located.
roads
type section
fault
scale
1 mile
DALMENY
KIANGA POINT
WAGONGA
NAROOMA
BOGOLO HEAD
MYSTERY BAY
lake
306000
519000

of chlorite, biotite, muscovite, quartz and occasionally, a few grains of albite. These are stained with limonite, which is generally a weathering product. No primary flow structure has been recognised, although secondary metamorphic minerals are frequently aligned into a rough parallelism in a superimposed slaty cleavage.

Other lavas, such as those at the south end of Surf Beach (grid reference 15662925), now consist of a fine-grained weakly foliated rock within which are numerous dark green and brown elongate " bodies ", ranging in size from less than ½ inch to 7 inches in length. They are commonly elongate and flattened in the plane of foliation and plunge gently to the north west. Hobbs (1962, Figure 6b) refers to this rock as a conglomerate. Two varieties of these " bodies " are contained within a matrix of fine-grained biotite, muscovite, quartz and much goethite. The first type resembles a quartzite and consists of fine recrystallized quartz, muscovite and light green biotite. The second type is more abundant, consisting of elliptical rounded and angular mosaics of light green chlorite set in a very fine mesostasis of goethite, quartz, chlorite, green biotite, and white mica.

In her collection of rocks from the Narooma area, housed in the Department of Geology and Geophysics, University of Sydney, Dr. I. A. Brown has called several of these elongate masses, " boulders " (28249, 28251, 28258, 28259). In the writer's opinion, this rock is considered to be an amygdaloidal lava flow and the " boulders " represent deformed quartz-filled cavities and recrystallized glassy areas. The chlorite-rich " boulders " are amygdaloidal and the amygdales are often surrounded by a very fine mesostasis which may once have been a glass, for it is intersected by a number of curved cracks which could possibly represent perlitic cracks, now filled with limonite and hematite.

Volcanic breccias with a light brown weathered matrix are found along the northern cliff face of Surf Beach. Here they consist of ellipsoids or angular shaped masses which vary in length from ¼ to 6 inches, being elongate in the plane of the foliation and parallel to the local fold axis. In thin section they consist of albite, white mica and chlorite.

The breccias are commonly associated with the pillow lavas, an association which may suggest they are really pillow breccias formed by slumping and fragmentation of an unstable pile of pillows and tuff.

The Undifferentiated Greywackes

The sequence outcropping along the western margin of the area and in the northeast comprises an unknown thickness of thinly bedded, quartz-rich clastic sediments and minor pelites. The presence of ubiquitous graded bedding and an absence of cross bedding in the clastic material has allowed these rocks to be classified, using Packham's classification (1954), as members of a greywacke suite.

The greywackes along the coastal section are light brown to buff coloured, and inland they are commonly a light yellow-brown. The beds of greywacke vary from 6 inches to 6 feet in thickness. They are generally poorly sorted, medium to fine-grained rocks consisting of fragments of quartz, feldspar, muscovite and biotite set in a fine-grained recrystallized matrix of muscovite and quartz.

The quartz (25 to 75%) occurs as angular to sub-rounded detrital fragments, as large grains containing numerous subgrains, and as fine-grained recrystallized fragments. In the coarser greywackes, the inequant grains have their long axes lying parallel to the plane of bedding (e.g. 31168). The feldspar is commonly plagioclase, which comprises up to 2% of the total rock volume and is most abundant in the medium to fine-grained rocks, being rare in the coarse sediments. The plagioclase, An_7, is generally fresh and may also be found in association with small grains of microcline. Detrital plates of muscovite and biotite as well as a small percentage of pelitic rock fragments (e.g. 31169) are also present.

The pelites are rarely more than two feet thick and are generally subordinate to the greywacke beds. They are fine-grained, and consist of muscovite and quartz, together with occasional ragged, weakly pleochroic biotite plates. Generally they have been significantly altered by metamorphism and it is not certain whether the grain size now seen is the original or due to metamorphism.

Sedimentary structures are common and include graded bedding in the greywackes, current bedding in the pelitic rocks, together with sole markings, flame structures, and bedded units containing numerous intraformational mudstone fragments. These sedimentary structures only give the local facing of a bed. From the limited evidence available, the orientation of the formations within the Narooma fold are thought to be the right way up.

Discussion and Conclusion

The arenites and pelites of the Bogolo Formation appear to be conformable with the overlying Wagonga Formation.

The undifferentiated greywackes and pelites are lithologically distinct from the underlying Wagonga Formation. Nevertheless, there is no evidence for or against an hiatus between these two units and it is considered that they may be conformable.

Brown (1928) describes a similar chert-greywacke boundary at Bateman's Bay, as being unconformable and on this basis splits the sedimentary sequence into Upper Ordovician and Cambrian. A Cambrian age for these sediments is now open to question by the discovery of a graptolite of a (?) retiolid character by Dr. A. A. Opik, in shale from immediately above a chert layer. This was quoted by Sherrard (1962) but the specimen has since been destroyed by fire at the Bureau of Mineral Resources, Canberra. If this was a retiolid graptolite, then the chert sequence may be upper or middle Ordovician in age. Until more definite proof is available, the age of these sediments will still be open to question. The rocks of the Narooma area appear to be conformable and as such, could be Ordovician.

It is suggested that the presence of the persistent bedding and associated sedimentary structures in the greywacke may be explained in terms of turbidity current deposition in a geosynclinal environment. Such an environment would also be compatible with the formation of the cherts and the presence of basic volcanics.

The cherts, and especially those of the Bogolo Formation, may possibly represent a chemically precipitated deposit in a closed basin. The chert of the Wagonga formation probably represents a major accumulation, being interrupted by minor influxes of pelitic material and the extrusion of submarine lava flows and the deposition of tuff. This volcanism could have served as a major source for the precipitated silica.

The sedimentary sequence found in the Narooma area is probably part of the Lachlan Geosyncline (Packham, 1960) which in mainland eastern Australia is dominated by quartz-rich greywacke and pelitic rocks. Sedimentation would have been brought to an end by the Benambran Orogeny which is probably responsible for the major deformation of the area and the Narooma Fold. The fold is a large anticline plunging from 10 to 30 degrees to the NNW.

The Tertiary Deposits

These occur as isolated cappings on the small hills and cliff tops adjacent to the coast. Two principal rock types have been observed, an oligomictic conglomerate and a ferruginous sandstone, both occurring some 90 to 100 feet above the present sea level. There are no microfossils in these rocks or any other indication of their relative age, so they have been tentatively assigned to the Tertiary on a basis of similarity to deposits found further north (Brown, 1925).

The oligomictic conglomerates typically occur at grid reference 15733055 and are composed of angular fragments of chert varying from $\frac{1}{4}$ inch to 2 inches across set in a matrix of partially cemented ferruginous quartz sandstone. Other minerals found within the sandstone include small rhombs of calcite and grains of tourmaline, zircon and magnetite. Distinct current bedding may be observed in the finer layers and bedded units usually vary from 6 to 18 inches in thickness.

The complete absence of any marine Foramanifera and the abundance of small calcite rhombs tends to suggest that these rocks are shallow fresh water deposits, that have been deposited within a closed or semiclosed basin separated from the Tertiary shoreline by a low barrier.

Quaternary

The Quaternary System is represented in the area by river alluvium and recent unconsolidated beach sand deposits. The latter are generally bar-type deposits found between the coastal headlands and consist of two main types of sand. The higher and apparently older deposits consist of leached incoherent quartz sand with varying amounts of organic material. These older deposits also contain many lagoons now filled by fresh water swamp or estuarine sediments.

The younger Quaternary deposits are mainly the present day sand beaches that connect the rocky headlands, consisting of fresh quartz sand free of any organic material. Large recent sand accumulations also occur at the eastern end of the Wagonga Inlet in the vicinity of Narooma township.

Igneous Rocks

There have been three major phases of igneous activity in the area. These phases and the major rock types they produced are summarised below:

1. Devonian (?) ;
   (a) Fine-grained acid intrusive rocks.
   (b) Fine-grained basic intrusive and extrusive rocks.
2. Permian (?) ;
   Intrusive trachytes.
3. Cretaceous ;
   Intrusions associated with the "Shoshonite Suite"* of the Mt. Dromedary Complex.

Devonian (?) Igneous Rocks

The Acid Rocks. These occur as dykes intruding the deformed sediments and vary from 9 inches to approximately 100 feet in width ; individual dykes are seldom traceable for more than 500 feet. They are composed of a fine-grained, white quartz-rich rock, porphyritic in both quartz and plagioclase. The quartz (40%) is commonly intergrown with fine anhedral potash feldspar, both in the groundmass and as small spherulites. The plagioclase phenocrysts (7%) occur as prismatic and tabular crystals (approximately $1 \times 0 \cdot 5$ mm. across) ; their composition ranges from An_4 to An_{12}. Secondary alteration of a number of dykes has resulted in the conversion of much of the orthoclase into fine white mica.

The Basic Rocks. These are composed of both intrusives and a lava together with breccias, which unconformably overlie or intrude the folded sediments but predate the Permian and Cretaceous intrusions. The assignment of these rocks and acid volcanics to the Devonian is based partly on these stratigraphic relationships together with their similarity to the highly altered basalts, spilites and rhyolites of the Eden district (Brown, 1931, 1933).

Small, light green, well jointed and very weathered, epidotised basic rocks occur throughout the area. Two good examples of such rocks are found as a basaltic dyke at grid reference 12672960 and an amygdaloidal basalt outcropping at grid reference 104267.

The dyke material has an intergranular texture and consists of plagioclase (and pseudomorphs of chlorite), titanaugite, chlorite and clinozoisite, with accessory ilmenite, leucoxene and pyrite. The border phase of this dyke (e.g. 31186) exhibits a very pronounced variolitic texture consisting of titanaugite and interstitial chlorite. The plagioclase occurs as prismatic laths approximately 1 mm. long and is now generally completely pseudomorphed by a light green chlorite. The titanaugite has also been extensively altered and now consists of small remnant leucoxene-coated grains, approximately $0 \cdot 4$ mm. across, which are angular or prismatic in shape being separated from one another by thin aggregates of chlorite. Clinozoisite is ubiquitous, occurring as small aggregates or as individual grains approximately $0 \cdot 1$ mm. across.

The lava (e.g. 31156) is mineralogically identical to the epidotised basaltic dyke, except that the albite has not been completely chloritised and is present as elongate laths of approximately $0 \cdot 8$ to $0 \cdot 5$ mm. in length. This lava is also characterised by small spherical amygdales varying from $0 \cdot 4$ to $2 \cdot 5$ mm. in diameter. These amygdales are generally filled with anhedral grains of clinozoisite ($0 \cdot 1$ mm. across) together with large plates of albite or very fine chlorite.

Permian (?) Igneous Rocks

This group of intrusive rocks postdates the folding of the area and predates the Cretaceous rocks, with one of the latter apparently intruding the former at grid reference 10882601. No relationship between these and the Devonian rocks has been established. The tentative assigning of a Permian age to this group is on the basis of a magnetic survey. The trachyte dykes are the only rocks in the area to consistently show a negative magnetic polarity in comparison to a positive polarity in all other rocks. Although several occurrences of negative polarities have been reported from igneous rocks of the Tertiary period these are ruled out by the fact that the dykes appear to be intruded by the Cretaceous intrusions and are unconformably below the supposed Tertiary deposits.

A number of dykes consisting of trachyte occur throughout the area together with a larger intrusion at the north end of Surf Beach at grid reference 15553000. This intrusion appears to consist of two small plugs connected by a narrow discontinuous sill, along with two very weathered dykes. The contact of the intrusions with the volcanic sequence is indeterminable because of poor outcrop, but the chert-intrusion contacts are very clear. Dr. I. A. Brown has collected several specimens from this contact and refers to them as the "matrix of pillow lava", (Specimens 28262 to 28264).

It is considered that the intrusions are so distinct in composition and magnetic properties as to justify separating them from the deformed volcanics.

Two characteristic trachytic igneous rocks may be recognised in the area. One is porphyritic with an orthophyric groundmass and

* Using the terminology of Joplin, 1964.

the other has either an intersertal or pilotaxitic texture. In both types of rock the predominant feldspar is potassic with occasional crystals of plagioclase (An_8). The interstitial material is generally authigenic chlorite, opaque iron oxides, and varying amounts of carbonate and occasionally quartz. In the porphyritic rocks potash feldspar phenocrysts, which vary from 0·7 to 2 mm., are commonly heavily carbonated containing cores of white mica.

The Cretaceous Shoshonite Suite

A number of the dykes and two small stock-like bodies or monzonitic satellites found in the area appear to be related to the Cretaceous monzonite suite of Mount Dromedary (Evernden and Richards, 1962).

The Dykes

Other than those in the vicinity of Ohlsen's Creek (see below), the dykes are generally too weathered to obtain fresh material for thin section examination, except for a vogesite which occurs at grid reference 16002392. This dyke is porphyritic in hornblende and minor quantities of weathered plagioclase.

The Monzonitic Satellites

Two such intrusions have been found and these are similar to the Monzonitic Satellites described by Boesen (1964) to the south and west of Mount Dromedary. A small intrusion of micromonzonite outcrops to the south of Corunna Lake at grid reference 133219. This intrusion has been described by Purvis (1965) and is very similar to part of a larger body which outcrops in Ohlsen's Creek at grid reference 103260. The rock is locally inhomogeneous but is monzonitic in composition, consisting of porphyritic micromonzonite and monzonite.

Porphyritic Micromonzonite

In hand specimen this is a fine-grained rock varying from grey to dark greenish-grey with distinct phenocrysts of hornblende and less commonly pyroxene. The size of phenocrysts varies considerably throughout the intrusion, varying from 1 to 4 mm. and these phenocrysts are frequently found aligned sub-vertically. A similar arrangement of the long dimension of xenoliths of country and igneous rock is present indicating vertical flow during intrusion.

The porphyritic micromonzonite has variable quantities of hornblende, clinopyroxene and occasionally zoned plagioclase. The ground mass is a very fine-grained mass of potassic feldspar within which is included fine pyroxene, plagioclase and biotite, together with accessory magnetite, pyrite and apatite.

The plagioclase is confined chiefly to the groundmass as small euhedral prismatic crystals less than 0·1 mm. in length. Phenocrysts also occur as euhedral crystals and as fragments with a variation in size from 2·2 × 0·5 mm. to approximately 0·3 to 0·1 mm. The average composition of the plagioclase is andesine with a range of An_{30} to An_{48}.

Alkali feldspar is commonly confined to the groundmass as very fine-grained granular crystals and rarely occurs as phenocrysts. Very small laths of carlsbad-twinned orthoclase (2V 70°) are to be observed intergrown with pyrite (e.g. 31182), apparently formed by late crystalization of locally concentrated alkali-rich portions of the magma.

Hornblende may occur: (1) as primary euhedral or subhedral phenocrysts or fractured, embayed and corroded fragments; (2) as a reaction product of clinopyroxene. The phenocrysts of primary hornblende occur either as large (5 × 0·5 mm. to 0·3 × 0·1 mm.) euhedral crystals or as small glomeroporphyritic aggregates. The hornblende is commonly zoned and may contain small inclusions of pyroxene, plagioclase or magnetite. It is generally moderately pleochroic, as in 31158, with:

X = yellow		$X<Y<Z$
Y = olive		$\hat{ZC} = 24°$
Z = brown		2V — ve

The second type of hornblende is generally a reaction product formed by an almost complete replacement of the clinopyroxene parallel to the pyroxene cleavage (e.g. 31179, 31183). This hornblende has a pleochroism from greenish yellow to deep olive-green.

X = yellow		$X<Y<Z$
Y = greenish yellow		$\hat{ZC} = 25°$
Z = olive		2V — ve

The clinopyroxene is commonly colourless or pale green and non-pleochroic, occurring as euhedral phenocrysts or fragments thereof, varying from 0·05 × 0·1 mm. in the finer-grained rocks, to 0·4 × 0·5 mm. in the coarser rocks. In the groundmass, the clinopyroxene generally occurs as small fine-grained aggregates or as small prismatic crystals.

A red brown biotite is found as phenocrysts up to 2 mm. in length (e.g. 31183), commonly kinked and bent, and occurs as isolated crystals or is moulded around grains of pyroxene. Edges are generally ragged (e.g. slides 31179b and c) and they may be replaced by chlorite which generally extends along the basal plane of the biotite dividing it into a series of alternating chlorite-biotite layers.

Monzonite

The monzonite is intimately associated with the porphyritic micromonzonite and tends to have gradational boundaries. The rock is a light grey to dark green-grey in colour and two main varieties may be observed in the field. One is deficient in mafic minerals while the other is composed mainly of mafic constituents. Both show local monzonitic texture with optically continuous plates of alkali feldspar enclosing laths of plagioclase and mafic constituents as in 31191. All specimens contain alkali feldspar and plagioclase with varying quantities of biotite, hornblende and pyroxene. Accessories include apatite, magnetite and pyrite. Calcite and chlorite are frequently observed as alteration products of the plagioclase and hornblende.

Plagioclase generally occurs as subhedral prismatic laths ranging in composition from An_{52} to An_{40}. These are commonly zoned with calcic andesine cores and margins which appear to be partially replaced by orthoclase.

The hornblende is light green and is commonly replaced in part or wholly by small flakes of strongly pleochroic light brown biotite. The hornblende occurs as anhedral to subhedral grains averaging from $2 \cdot 5 \times 1$ mm. to 1×1 mm.

Xenoliths

The monzonites and porphyritic micromonzonites contain two types of xenoliths: (1) fragments of the country rock, and (2) early phase xenoliths.

The country rock xenoliths include chert, which has been completely recrystallized into a mosaic of fine interlocking grains of quartz; psammites which now consist of a mixture of fine quartz, biotite, pyroxene, plagioclase, and orthoclase; and the basaltic rocks which retain their ophitic texture and have biotite in the place of primary ferromagnesian minerals.

The early phase xenoliths are generally small, elliptical bodies of up to 4 inches in length, and are either monomineralic or consist of fragments of other monzonitic phases. Three types of early phase xenoliths have been recognised, (1) hornblendite, (2) pyroxenite and (3) layered plagioclase-rich xenoliths.

The hornblendite xenoliths are coarse-grained and consist of anhedral crystals up to 3 mm. in length. The hornblende contains numerous well developed, euhedral crystals of colourless and pink apatite up to $2 \cdot 7 \times 0 \cdot 2$ mm., together with small dendritic plates and aggregates of magnetite, apparently exsolved from within the crystal.

In the pyroxenite xenoliths the pyroxene consists of an interlocking granular mass of squat, subhedral crystals which occasionally possess slightly rounded outlines (31179). The average grain size of the pyroxene varies from $1 \cdot 8$ mm. to $0 \cdot 5$ mm. across.

The layered plagioclase-rich xenoliths consist of parallel layers of plagioclase, approximately 2 mm. wide, alternating with discontinuous lenses composed of fine-grained pyroxene, biotite, hornblende and opaque grains. The plagioclase occurs as tabular, subhedral grains of approximately $0 \cdot 2 \times 0 \cdot 1$ mm., the long axes of which are aligned parallel to the plane of the layering. The composition of the plagioclase is calcic labradorite, An_{65} to An_{70}.

The mafic layers formerly were composed of fine, granular masses of subhedral, pale green pyroxene, averaging $0 \cdot 3 \times 0 \cdot 1$ mm., and pale poikilitic biotite, which are very strongly pleochroic. The layers now contain remnants of pyroxene, the bulk of which has been converted into a dark biotite, magnetite and an olive green hornblende (31184).

The occurrence of layered plagioclase xenoliths has also been noted in the other monzonitic satellites to the south and west of Mount Dromedary (Boesen, 1964). These latter, and the Ohlsen Creek xenoliths, appear to be identical with the laminated feldspar pyroxenite described by Boesen (1964). The conclusion reached by Boesen was that the pyroxenite existed prior to monzonitic rocks, and was possibly an accumulate, formed by differential settling within the original magma chamber.

The contact metamorphism associated with the monzonitic satellites is of hornblende hornfels facies and is found in aureoles up to 20 feet in width in the surrounding volcanics, cherts and pelites. The metamorphism of the carbonate-chlorite rich volcanic sequence has resulted in such rocks as garnet-diopside, and diopside-hornblende hornfelses, often with the preservation of the original vertical layering. The cherts and pelites have in general suffered little metamorphism, but appear to be indurated.

Economic Geology

The only mineral of economic importance that has been mined in the Narooma area is gold, although limited mining for turquoise, the first to be found in New South Wales, was carried out in the north of the area from 1894 at the Mount Lorigan Mine (Curran, 1896).

The main gold mineralisation in the area is along the Easdown Line (grid reference 12103200), where the main acid (rhyolitic) dyke parallels the strike of the cherts, but varies

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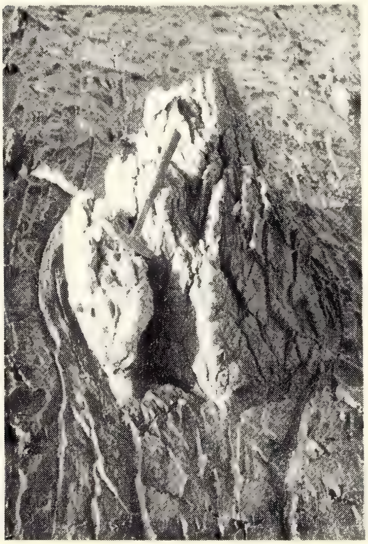

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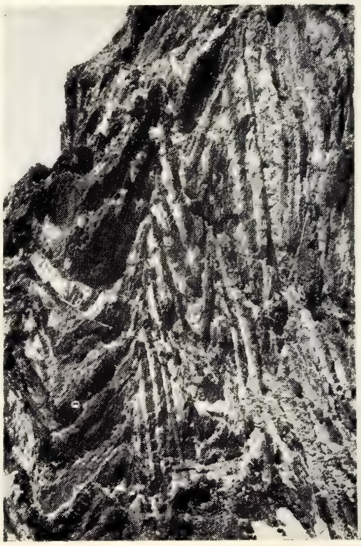

6

greatly in thickness from 5 to 120 feet. Associated with the main dyke are numerous small lenticular bodies of rhyolite. The dykes have been extensively sericitised and pyritised (e.g. 31185) and are commonly weathered to mixtures of quartz, clay and sericite to a depth of 40 feet or more. They assay from 2 to 10 dwt of gold per ton (Ann. Rept. Department of Mines, 1906, p. 22).

The pyrite is normally confined to the centre of the dykes and these are the only parts that have been mined in the past, the margins are normally devoid of pyrite. The pyrite is finely disseminated throughout the rhyolites occurring as hypidiomorphic crystals of no more than 4 mm. across with an average diameter of 1·5 mm., and is closely associated with the white mica. Polished sections show no evidence of any free gold on the surface of the pyrite crystals, suggesting the gold may be contained within the lattice structure of the pyrite. The only free gold associated with the rhyolites, is that found in the oxidised zone of the open cuts and on the faces of joints and quartz veins which are invariably coated with iron oxide.

Acknowledgements

The writer wishes to thank Professor C. E. Marshall for making laboratory facilities available and is indebted to the members of staff of the Department of Geology and Geophysics, University of Sydney, for helpful and stimulating discussions on the various aspects dealt with in this paper. In particular, I would like to express my gratitude to Dr. B. E. Hobbs and Dr. R. H. Vernon and Messrs. V. J. Wall and P. F. Williams for criticism and discussion of various sections in the manuscript.

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Explanation of Plate 1

Fig. 1.—Large chert lens within the pelitic rocks of the Bogolo Formation at grid reference 16082805.

Fig. 2.—A planar section in an altered pillow lava at the north end of Surf Beach, i.e. grid reference 15502972.

Fig. 3.—Volcanic breccia stratigraphically overlying the pillow lava in figure 2 at the north end of Surf Beach.

Fig. 4.—A strong metamorphic layering in the Bogolo Formation showing its lenticular nature and the presence of small remnants of arenite beds, which now occur as the lighter coloured lenses at grid reference 16322480. The darker material consists of a well foliated pelitic material.

Fig. 5.—A boulder in the well foliated pelite of the Bogolo Formation at grid reference 16382468.

Fig. 6.—V-shaped folds plunging 20 degrees towards the south at grid reference 15782860. This type of folding is characteristic of the pelitic cherts of the Wagonga Formation.

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The Geology of the Manildra District, New South Wales

N. M. Savage

Abstract.—An investigation of the geology immediately south of Manildra, N.S.W., shows that six formations of Silurian and Lower Devonian age can be mapped in the area. The Cudal Group, described by Ryall (1965) in the Canowindra area, is redefined and extended northwards to include three new Silurian formations, the Greengrove Formation, the Kurrajong Park Formation, and the Mackey's Creek Shale. Overlying these are further new units consisting of the Siluro-Devonian Fairhill Formation, and the Lower Devonian Maradana Shale and Mandagery Park Formation. The Garra Formation of Strusz (1965*a*) is included with the Maradana Shale and the Mandagery Park Formation in the new Gregra Group. Graptolites show the age of the Cudal Group deposits to range from the middle Llandoverian to the middle Ludlovian. The overlying Fairhill Formation appears to extend well into the Gedinnian. A middle to late Gedinnian age is assigned to the Maradana Shale, and an early Siegenian age to the Mandagery Park Formation, largely on the evidence of the brachiopod and conodont faunas present. A correlation of the Cowra Trough sediments is proposed based on the faunas, the distribution of the sediments, and the igneous and tectonic evidence in this part of the Lachlan Geosyncline.

Introduction

The Lower Palaeozoic deposits of the Manildra district form part of the Cowra Trough sediments of the Lachlan Geosyncline. Within this depositional trough, bordered to the west by the Parkes Platform and to the east by the Molong Geanticline, a thickness of almost 10,000 feet of Silurian and Lower Devonian sediments accumulated. Previously the faunas from these rocks have received little attention and the stratigraphy has been poorly understood. Work in the Manildra district was begun by the writer in 1962 in an attempt to establish well defined stratigraphic units within this part of the Cowra Trough and to examine the faunas which occur there. The task of describing the rich fossil assemblages is now well advanced and it is hoped to publish the results in the near future.

Location

The area investigated comprises about 40 square miles immediately to the south of Manildra, a small town 195 miles west of Sydney on the Parkes road. It is bordered to the west by the thickly wooded Upper Devonian Mandagery Ranges and another belt of largely uncleared country, coincident with the Upper Devonian Catombal Group, forms a conspicuous north-south strike ridge to the east. These bounding ranges rise to between 2,000 and 2,500 feet. The older sediments between are of Silurian and Lower to Middle Devonian age and outcrop less prominently to form a broad tract of good agricultural country varying in altitude between 1,100 and 1,700 feet. The district is drained by Mandagery Creek which flows southwards through Manildra and eventually joins the Lachlan River.

Previous Investigations

In the latter half of the last century the Manildra district attracted attention when gold, copper and tin were found in the vicinity of the Gumble Granite to the north. Short geological reports were prepared for the State Department of Mines by Wilkinson (1885, 1886) and Anderson (1888) but no regional mapping was attempted. In 1903 Etheridge described a *Rhizophyllum* which had been collected from limestones 2 miles north-east of Cudal, a town 9 miles south of Manildra, and in 1919 Carne and Jones briefly reported on the limestone outcrops to the north and north-east of Cudal as part of a state-wide survey of limestone deposits. No comprehensive report on the stratigraphy and structure of this region was attempted until Joplin and Culey published a short paper on the Molong-Manildra district in 1938. These latter workers recognized the general relationships of the Palaeozoic rocks in a broad belt of country extending from Cumnock in the north to Cudal in the south and they first proposed the name Manildra Beds for the tuffaceous sediments in

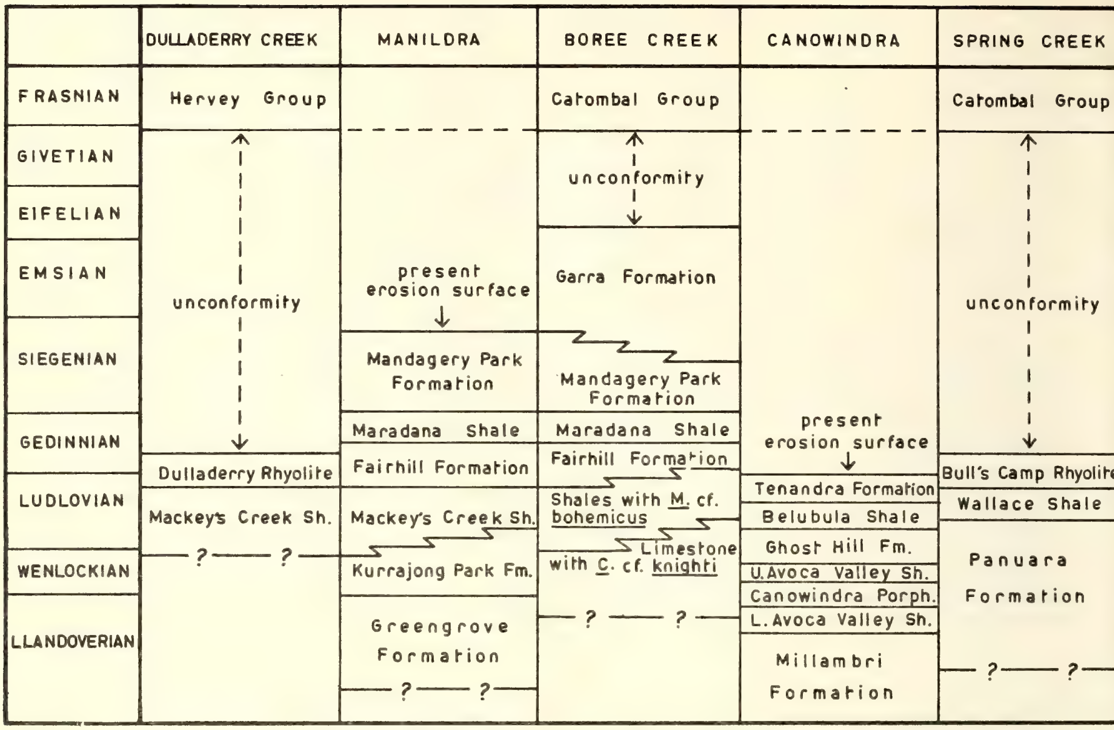


FIG. 1. Correlation chart of selected Silurian and Devonian sequences in the Cowra Trough.

the area. However, Joplin and Culey did not recognize the presence of important major strike faults and this profoundly effected their detailed interpretation of the geology.

Work of major importance in establishing the Lower to Middle Devonian age of the Garra limestones immediately to the east was carried out by Hill and Jones (1940), and Hill (1942), using corals from the Molong and Wellington districts north-east of Manildra. In 1950 Stevens published a large-area reconnaissance map of the country south of Cudal and more recently Struss (1965*a*, 1965*b*, 1966) has described the Garra Formation in detail and described many of the corals from the limestones.

Geological Structure and Stratigraphy

The geology of the Cowra Trough is dominated structurally by numerous north-south strike faults. Two of these, the Cudal and Manildra Thrusts, form the east and west boundaries of the area investigated and between them the rocks are folded into a broad syncline and anticline (Fig. 2). The succession is exposed on the westerly dipping limb between the axes of these folds. Here the dips vary from 30 to 50 degrees with very little variation in the NNE–SSW strike except in the vicinity of the granite intrusion immediately south of Manildra. The stratigraphic subdivisions recognized in the area are shown below.

Upper Devonian Catombal Group

— Major Unconformity —

Eifelian		
Emsian	Garra Formation (over 5,000′)	Gregra Group
Siegenian	Mandagery Park Formation (over 1,700′)	
	Maradana Shale (1,000′)	
Gedinnian	Fairhill Formation (3,500′)	
Ludlovian	Mackey's Creek Shale (450′)	
Wenlockian	Kurrajong Park Formation (1,200′)	Cudal Group
Llandoverian	Greengrove Formation (over 1,400′)	

Cudal Group.—In the Cudal area this Group is approximately equivalent to the " Molong Beds " of Joplin and Culey (1938) and to the

" Cudal Shale " of Stevens (1950). Each of these earlier terms was used to designate units several thousands of feet thick, consisting of very important graptolitic lithologies deposited during the greater part of the Silurian. As such they were broadly defined, and when mapped covered many hundreds of square miles.

In more recent years a greater degree of subdivision has become possible and the earlier names have been modified. The term " Molong Beds " was inappropriate for the shales and limestones immediately north of Cudal, for these sediments do not form a continuous belt through to the Molong limestones as first supposed by Joplin and Culey, nor are the faunas in the two limestones similar as was earlier believed. The " Cudal Shale " of Stevens was a more satisfactory name and it has been retained in a modified form as the Cudal Group of Ryall (1965). As used by Ryall the Group comprised the complete succession of Silurian sediments exposed east of Canowindra, a town some 20 miles south of Cudal. In that area the Silurian is relatively well represented and the Cudal Group includes a succession of shales and siltstones with occasional limestone lenses. Similar sedimentary conditions were in existence in the Cudal area.

It is proposed herein to restrict the Cudal Group to those predominantly argillaceous Silurian sediments originally included in the " Cudal Shales " of Stevens but underlying the " Manildra Beds " of Joplin and Culey (1938). The Group would thereby include the Avoca Valley Shale, Ghost Hill Formation and Belubula Shale, in the Canowindra area, and the Greengrove Formation, Kurrajong Park Formation and Mackey's Creek Shale, in the Cudal area. Excluded are the arenites, siltstones and shales of Ryall's Tenandra Formation ; these are of uncertain age but are known to overlie the *Monograptus bohemicus* horizon and could well be equivalent to the volcanic greywackes and tuffaceous sandstones overlying the *M. bohemicus* horizon in the Cudal area.

(*a*) *Greengrove Formation.* This is a new formation name and it is proposed for the belt of shales and limestones which outcrop along the axis of the Cudal Anticline and which are particularly well exposed on the Greengrove property, 3 miles north-west of Cudal (Fig. 2). The beds are the oldest in the area and contain a graptolite fauna of Llandovery age. The type section for this formation is along the line A-B, as shown in Fig. 2, where a thickness of 1,420 feet consists of :

600′ Hard olive-brown shale.
230′ Poorly exposed grey and buff shale.
90′ Grey limestone with *Trimerella.*
170′ Poorly exposed grey-brown shale.
90′ Light grey limestone with *Trimerella.*
240′ Poorly exposed brown and olive shale.

The base of the formation is not known and the total thickness is therefore something in excess of the above figure.

The shales vary considerably in colour, composition and hardness. One of the lowest exposures of the formation is at Locality 19 where grey, brown, and olive shales occur. These split relatively easily along the bedding and contain abundant fine detrital quartz and mica. *Rastrites* sp. has been collected from this horizon.

Somewhat higher in the formation at Locality 12 the shales are olive-brown in colour and less fissile. Here fragments of *Glyptograptus tamariscus* have been found. Close to the top of the formation *Retiolites* sp. and *Monograptus priodon* are present in quartz-rich, darkly banded, grey shales.

Limestone lenses occur in the Greengrove Formation at several horizons. The inarticulate brachiopod *Trimerella* sp. is characteristic of these limestones. Also common are the corals *Favosites* sp. and *Halysites* sp.

The graptolites in this formation suggest an age ranging from lower Llandoverian, in the lowest parts exposed, to late Llandoverian or early Wenlockian, at the top. *Trimerella* is known only from the middle Silurian of Europe and North America.

No sedimentary structures have been observed which might indicate the direction of current movement during the deposition of this formation but the fine banding of the shales and the general north-south distribution of the limestone lenses suggests quiet, shallow-water conditions, possibly along a north-south shore line.

The Greengrove Formation has been mapped to the north of the area and is exposed between the town of Garra and the Gumble Granite. Here several *Trimerella* bearing limestone lenses occur. This useful brachiopod is also present in a small pocket of limestone to the south-west of the area where Llandoverian rocks have been upthrown by the Manildra Thrust.

(*b*) *Kurrajong Park Formation.* This formation is named after Kurrajong Park property, 5 miles north of Cudal, where it outcrops prominently. It consists of about 1,200 feet of

siltstones and interbedded greywackes, and lies conformably between the Greengrove Formation below, and the Mackey's Creek Shale above. Details of the lithologies along the type section A-B are shown below.

200′ Greenish-grey coarse siltstone.
50′ Coarse greywacke.
70′ Greenish-grey siltstone.
190′ Coarse greywacke with intermediate volcanic fragments.
150′ Brown and black hard siltstone.
40′ Coarse greywacke.
100′ Grey-blue siltstones and shales.
260′ Light olive-brown shales and cherts.
130′ Hard brown siltstone.

The formation is characterized by a predominance of siltstones and greywackes. The basal siltstone unit is particularly hard and forms a conspicuous ridge through the area. The greywackes commonly contain coarse fragments of intermediate igneous rock and also calcareous organic fragments.

As with some of the overlying formations there is a gradual change in lithology from north to south, with the coarser sediments thinning in that direction. The greywackes pass imperceptibly into tuffs and shales which are often highly lithified, assuming chert-like characteristics and braking with a conchoidal fracture.

In Pine Gully, at Locality 18, the brachiopods *Rhipidium* and *Conchidium* occur with the graptolites *Monograptus* cf. *dubius*, *M.* cf. *flemingi* and *M.* cf. *testis*. Further north, at Locality 13, more specimens of *M.* cf. *dubius* and *M.* cf. *flemingi* have been collected, and the same two forms are again present north of the area shown on the map, at a locality on Mandagery Creek 200 yards upstream from the point where it is joined by Gumble Creek. At all three localities the same distinctive darkly banded lithology is present and it is likely that during this phase of deposition quiet conditions were widespread throughout this part of the Cowra Trough.

The graptolites present indicate a late Wenlockian age for the middle and upper parts of the Kurrajong Park Formation. Nothing is known of the origin of the sediments but the presence of large areas of *Conchidium* bearing late Wenlockian limestones in the Molong and Borenore districts about 10 miles to the east suggests that the sea floor shallowed in that direction. Deposition of material from the east seems unlikely however, for there was probably very little dry land exposed along the Molong Geanticline during Wenlockian time and a westerly source for these sediments is more likely.

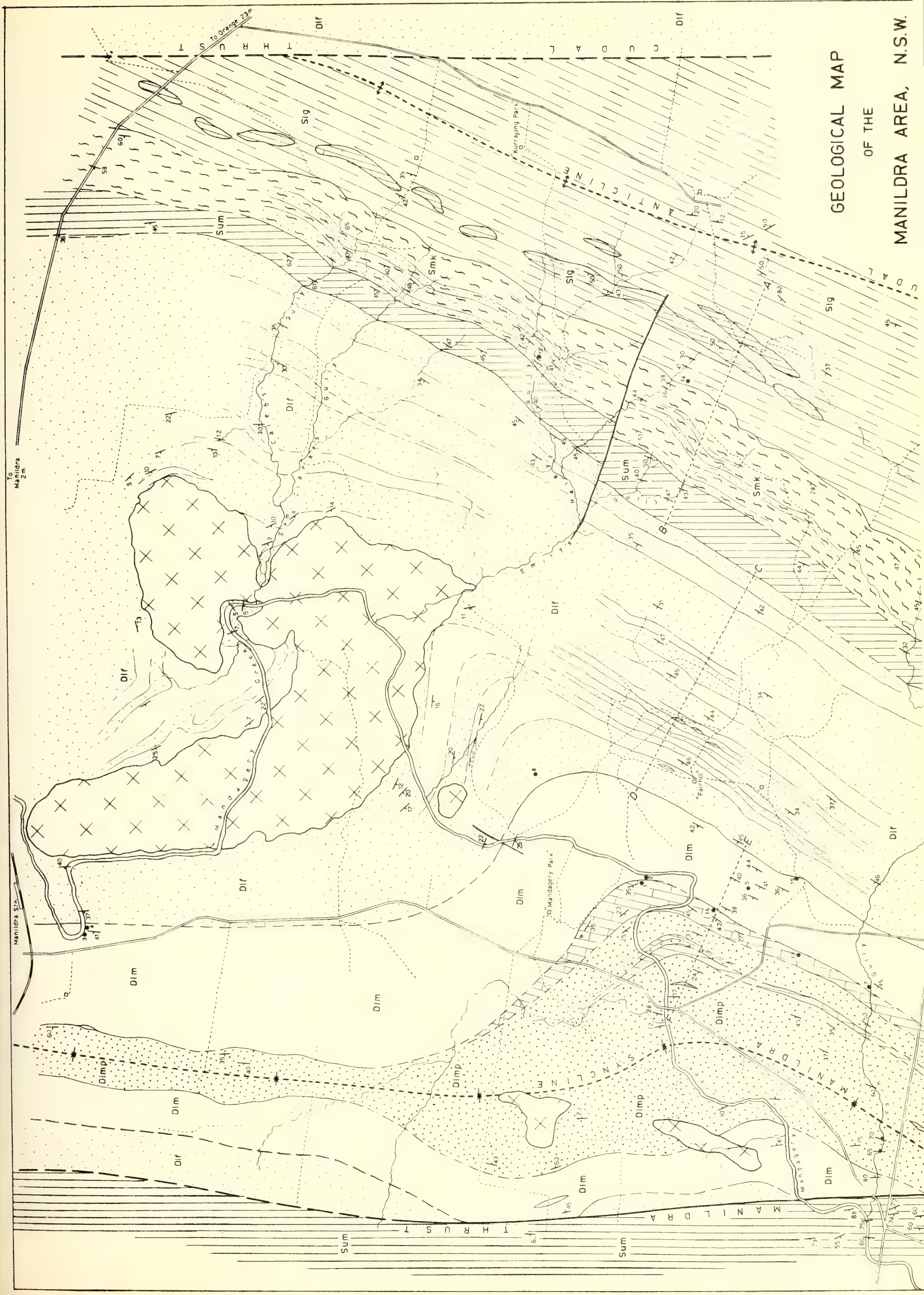
(*c*) *Mackey's Creek Shale.* This formation was first described by Stevens (1954) and is well exposed along Mackey's Creek, 4 miles south of Manildra. Stevens' conclusion that these shales were of late Silurian age was confirmed during the present work when specimens of *Monograptus* aff. *bohemicus* were collected at Locality 11, 1 mile downstrike from Mackey's Creek.

The shales and siltstones which occur further east, along type section A-B, are less highly cleaved than those exposed in Mackey's Creek but nevertheless have a similar grey-brown colour and are equally rich in fine detrital quartz and mica. No specimens of *M.* aff. *bohemicus* have been found in the vicinity of section A-B but have been reported by Maggs (1963) where the formation is exposed further north, at the junction of Gumble Creek and Mandagery Creek.

The Mackey's Creek Shale commonly outcrops as prominent ridges, devoid of trees and littered with micaceous grey flags. Similar fissile shales containing *M.* aff. *bohemicus* occur 10 miles to the east and they have also been reported from the Canowindra area 20 miles to the south (Ryall, 1965), and the Mumbil area 45 miles to the north (Strusz 1960). The widespread development of this fissile micaceous shale throughout the Cowra Trough indicates relatively uniform sedimentary conditions during the late Silurian. The Molong Geanticline was possibly totally submerged at this time and a westerly origin for the sediments seems probable.

Fairhill Formation.— The name "Fairhill Breccia" was proposed by Stevens (1954) for the tuffs and greywackes which overlay his "Cudal Shale" in the vicinity of Manildra. Stevens discarded the term "Manildra Beds" of Joplin and Culey and the boundaries of his unit by no means coincide with those of the earlier workers. The Fairhill Formation as proposed herein comprises only the lower part of the "Fairhill Breccia" and the "Manildra Beds". Although breccia horizons, with angular rock fragments an inch or more across, are present near the top of the formation, in general the textures are finer and the name "Breccia" has not been retained for the unit in its modified form.

The succession is particularly well exposed on the Fairhill property, 3 miles south of Manildra. It consists of breccias, greywackes,


GEOLOGICAL MAP
OF THE
MANILDRA AREA, N.S.W.
To Orange 23m
To Manildra 2m
Manildra Stn.
Kurrajong Park
"Mandagery Park"
"Fairhill"
CUDAL THRUST
MANILDRA THRUST
Sig
Smk
Sum
Dlf
Dlm
Dlmp


GEOLOGICAL MAP
OF THE
MANILDRA AREA, N.S.W
Scale in miles
LEGEND
Siegenian
Gedinnian
Ludlovian
Wenlockian
Llandoverian
Dimp Mandagery Park Formation
Dlm Maradana Shale
Dlf
Sum Mackey's Creek Shale
Smk Kurrajong Park Formation
Slg Greengrove Formation
Gregra Group
Cudal Group
Carboniferous granite
Siluro Devonian dolerite
GEOLOGICAL BOUNDARIES
FAULTS
FOLDS
MANILDRA THRUST
MANILDRA SYNCLINE
CUDAL ANTICLINE
CUDAL THRUST

FIG. 1

tuffaceous sandstone, siltstones, and shales, with the greywackes and tuffaceous sandstones predominating. A total thickness of about 3,500 feet is developed along the type section C-D, but the formation reaches its maximum thickness 3 or 4 miles further north where the greywacke beds are particularly prominent and outcrop as conspicuous ridges or lines of large boulders. South of the Cudal-Manildra road the shale and siltstone beds become more evident and the coarser beds thin markedly. Along the measured section the following succession is exposed.

- 530′ Course tuffaceous sandstone with abundant brachiopods.
- 160′ Felspathic shales and tuffs.
- 60′ Coarse tuffaceous sandstone.
- 110′ Felspathic shales and tuffs.
- 60′ Coarse tuffaceous sandstone.
- 120′ Poorly exposed brown shale.
- 40′ Very coarse tuffaceous sandstone.
- 80′ Brown micaceous shale containing plant fragments.
- 100′ Buff shale with coarse felspathic fragments.
- 310′ Coarse greywacke and tuffaceous sandstone.
- 270′ Poorly exposed siltstone with interbedded greywacke.
- 260′ Poorly exposed greywacke with interbedded siltstone.
- 160′ Dark grey siltstone with some interbedded greywacke.
- 770′ Coarse greywacke with acid and intermediate fragments.
- 140′ Brown siltstone.
- 120′ Chocolate siltstone.
- 230′ Coarse greywacke with acid and intermediate fragments.

The greywackes and tuffaceous sandstones are greenish-grey when fresh but weather to a pale grey or brown. Thin sections made from them show the presence of abundant trachyte and plagioclase fragments along with many angular quartz grains. Some alteration to epidote and chlorite is evident. In the higher horizons the volcanic fragments are more often rhyolitic than trachytic with large quartz crystals and devitrified glassy fragments common. Some of these quartz crystals are deeply corroded and closely resemble quartz present in the quartz-felspar porphyries and rhyolites 3 miles west of Manildra. General stratigraphic evidence suggests that these nearby flows are of late Silurian or early Devonian age.

Interbedded with the greywackes and tuffaceous sandstones in the lower part of the formation are brown and grey siltstones which outcrop less prominently than the greywackes but are nevertheless very hard and well lithified. Higher in the formation beds of soft micaceous shale occur. These are olive-green when fresh but weather to a pale-brown colour, often with deep-brown surfaces to the bedding planes.

Occasional limestone lenses are present near the top of the Fairhill Formation and the Cowra Trough was probably shallowing at the close of the Silurian. In the uppermost horizons, brachiopods, trilobites, and gastropods are numerous and are commonly found associated with fragments of vascular plants. The coarseness of some of the rock inclusions in the greywackes, together with the presence of vascular plant material, suggests that land was very near, perhaps only a few miles from Manildra.

A fauna from Localities 8 and 9, near the top of the Fairhill Formation includes *Dolerorthis* cf. *persculpta* Philip, *Isorthis* cf. *festiva* Philip, *Schizophoria* sp., *Dalejina* aff. *frequens* (Kozlowski), *Gypidula* sp., *Machaeraria* sp., *Stegerhynchus* sp., *Leptaena* sp., *Plectodonta bipartita* (Chapman), *Quadrithyris* sp., *Eospirifer parahentius* Gill, *Howellella* cf. *scabra* Philip, *Atrypa* cf. *reticularis* (Linnaeus), *Spirigerina* cf. *supramarginalis* (Khalfin), *Meristella* sp., *Nucleospira* sp., *Crotalocephalus silverdalensis* Etheridge and Mitchell, *Ctenodonta raricostae* (Chapman), *Pleurontotus* sp., *Ptychocaulus* sp., *Loxonema* sp., *Tryplasma* sp., *Favosites* sp., *Cladopora* sp., and vascular plant fragments.

These forms suggest a Lower Devonian age but are not sufficiently diagnostic to give the horizon more precisely. However, overlying faunas suggest that the upper part of the Fairhill Formation was deposited during Lower and Middle Gedinnian times.

Gregra Group.—It is proposed that this group should consist of the Maradana Shale, the Mandagery Park Formation, and the Garra Formation. The first two are new formations comprised of sediments which formed the upper part of the " Manildra Beds " of Joplin and Culey. The third is the relatively well known sequence of calcareous deposits, extending from Cudal to Wellington, which has been successively named the Garra Beds (Joplin and Culey, 1938), the Garra Series (Browne, 1950), and the Garra Formation (Strusz, 1965).

All three formations are calcareous, shallow water deposits with rich shelly faunas. The

Garra Formation is not present immediately south of Manildra, probably because of erosion, and it is not considered here in detail.

The lower two formations of the Gregra Group will now be described from the type area south of Manildra.

(*a*) *Maradana Shale*. This formation conformably overlies the Fairhill Formation and, where well developed, consists of about 1,000 feet of hard, olive-green, calcareous shale. At its base it is well bedded and weathers easily, becoming buff in colour and soft enough to be easily broken. In contrast, the middle part of the formation is more lithified, and the bedding is often difficult to recognize because of the development of a strong cleavage and conchoidal fracture surfaces. This part of the shale weathers more slowly and has a characteristic blue-green colour. The formation becomes more calcareous towards the top and in the type area it passes upwards into the basal limestone of the Mandagery Park Formation, the transition taking place within a thickness of about 10 feet.

The Maradana Shale outcrops on both sides of the Manildra Syncline and can be easily followed in a north-south direction for about 10 miles. In the type area, and in the immediate vicinity of Manildra, the shale is relatively undeformed, but to the north and south where the folding is more intense, it is splintery and much fractured.

The formation is very fossiliferous, particularly in the lower horizons just above the underlying tuffaceous sandstone. A large variety of brachiopods, trilobites and corals has been collected from Localities 3 and 4 close to Manildra, and the same horizon can be picked up at Locality 15, near the type section. The fossils identified from these localities include *Dolerorthis* cf. *persculpta* Philip, *Isorthis* cf. *allani* (Shirley), *Resserella elegantuloides* (Kozlowski), *Sphenophragmus* sp., *Dicoelosia* sp., *Dalejina* aff. *frequens* (Kozlowski), *Schizophoria*, sp., *Muriferella* sp., *Gypidula victoriae* Chapman, *Leptaena* sp., *Notoleptaena* aff. *otophera* Gill *Megastrophia* (*Protomegastrophia*) sp., *Mesodouvillina* cf. *subinterstrialis* (Kozlowski), *Maoristrophia banksi* Gill, *Schuchertella* sp., *Plectodonta bipartita* (Chapman), *Chonetes* cf. *creswelli* Chapman, *Notanoplia australis* (Gill), *Machaeraria* sp., *Parapugnax* sp., *Quadrithyris* sp., *Eospirifer parahentius* Gill, *Cyrtina* sp., *Howellella* cf. *scabra* Philip, *Megakozlowskiella cooperi* (Gill), *Atrypa* cf. *reticularis* (Linnaeus) *Atrypina* sp., *Ogilviella* sp., *Spirigerina* cf. *supramarginalis* (Khalfin), *Lissatrypa lenticulata* Philip, *Meristella* sp., *Nucleospira* sp., *Gravicalymene angustior* (Chapman), *Crotalocephalus silverdalensis* Etheridge and Mitchell, *Phacops* sp., *Leonaspis* sp., *Otarion* sp., *Rhizophyllum* cf. *enorme* Etheridge, *Pleurodictyum megastoma* M'Coy, *Pleurodictyum* cf. *selcanum* Giebel, *Favosites* sp., *Cladochonus* sp., *Coenites* sp., *Heliolites* sp., *Cladopora gippslandica* (Chapman), *Cystiphyllum* cf. *australe* Etheridge, *Tryplasma columnare* Etheridge, *Cyricardinia* cf. *crenistria* (G. and F. Sandberger), *Ctenodonta raricostae* (Chapman), *Temnodiscus* sp., *Hederella* sp., *Fenestella* sp., *Actinostroma* sp., *Trupetostroma* sp., *Clionolithes* sp., and vascular plant fragments.

Towards the middle of the formation, at Localities 2 and 7, stropheodontids and schuchertellids abound. The fossils collected include *Isorthis* cf. *festiva* Philip, *Resserella* sp., *Schuchertella* sp., *Mesodouvillina* cf. *subinterstrialis* (Kozlowski), *Leptaena* sp., *Chonetes* sp., *Parapugnax* sp., *Cyrtina* sp., *Howellella* sp., *Quadrithyris* sp., *Atrypa* cf. *reticularis* (Linnaeus), *Spinatrypa* cf. *fimbriata* (Chapman), *Otarion* sp., *Acinopteria* sp., *Rhizophyllum* sp., and *Syringopora* sp.

The total fauna suggests a mid Gedinnian to early Siegenian age for the Maradana Shale and this is supported by conodont evidence from the lower horizons of the succeeding formation.

Several of the forms are conspecific with fossils described from the Tyers area of Victoria (Philip, 1962). The genus *Muriferella* has not previously been found so low in the Devonian and *Parapugnax* and *Sphenophragmus* are both typically Middle Devonian genera. However, associated with these forms are many species known from the Gedinnian of Victoria.

Further richly fossiliferous exposures of the Maradana Shale can be recognized north of the Gumble Granite, about 15 miles from Manildra, and again between the Garra Formation and the Siluro-Devonian volcanics in the Cheeseman's Creek area 10 miles to the east. Any attempt to show a wider distribution of the formation away from the type area would be largely dependant on detailed palaeontological work, for similar olive-green shales are frequently present in the overlying Garra Formation. Furthermore, rapid facies changes are a characteristic of the Lower Devonian sediments in the Cowra Trough and widespread correlation on solely lithological grounds is of doubtful value.

(*b*) *Mandagery Park Formation*. This formation, which conformably overlies the Maradana Shale, takes its name from the

Mandagery Park property, 2½ miles south of Mandildra. It consists largely of interbedded limestone and tuffaceous sandstone but occasional thin shale bands are present. The formation has its maximum development in the type area where over 1,600 feet is present. This consists of :

- 430′ Coarse red-brown lithic sandstone.
- 20′ Thinly bedded argillaceous limestone.
- 360′ Coarse red-brown tuffaceous sandstone.
- 120′ Well bedded grey limestone.
- 80′ Grey-brown tuffaceous sandstone.
- 40′ Well bedded grey limestone.
- 270′ Grey-brown tuffaceous sandstone.
- 350′ Well bedded grey limestone. Abundant silicified brachipods.

The upper part is unknown south of Manildra owing to erosion but 2 miles north-east of Cudal a thinner development of tuffaceous sediments, probably of the same age, can be seen to grade conformably upwards into the limestone of the Garra Formation.

The tuffs, which are reddish-brown in colour, have a low argillaceous content and consist mainly of acid igneous material. In the higher parts of the exposed sequence, along the axis of the Manildra Syncline, the proportion of detrital quartz and felspar increases markedly and the rock is more a lithic sandstone than a tuff. Fine conglomeritic bands are locally developed in these horizons and northerly dipping cross-bedding has been observed.

In thin section the tuffs can be seen to contain a good deal of altered material. Epidote, chlorite, and sericite are common, with the ferromagnesian minerals and potash-felspars being mainly effected in the absence of appreciable quantities of argillaceous material. Thin veinlets of secondary quartz are plentiful and probably represent recrystallization in fracture cracks during the later tectonic disturbances.

The presence of cross-bedded coarse sandstone at the upper horizons, together with occasional rounded pebbles up to 2 inches in diameter, suggests that the shore-line was not far distant at this time and that the Cowra Trough was shallowing. This was possibly associated with an upwarping of the landmass to the west and a consequent increase in erosion and sedimentation. However, this shallow-water sandstone phase was relatively localized and of short duration, for by the early Emsian limestone deposition was widespread.

The fauna from the basal limestone of the Mandagery Park Formation is of great interest. Many unusual forms are present and their silicified preservation makes possible the extraction of large numbers of good specimens. Brachiopods are by far the major constituent of the fauna but a number of corals, trilobites, gastropods, and conodonts are also present. The fauna includes *Dolerorthis* sp. nov., *Isorthis* cf. *festiva* Philip, *Anastrophia* aff. *magnifica* Kozlowski, *Gypidula victoriae* Chapman, *Schuchertella* sp. nov., *Machaeraria formosa* (Hall), *Eoglossinotoechia* cf. *cacuminata* Havlíček, *Zlichorhynchus* sp., *Parapugnax* sp. nov., *Quadrithyris* sp. nov., *Howellella* aff. *nucula* (Barrande), *Ambocoelia* aff. *praecox* Kozlowski, *Proreticularia* sp. nov., *Cyrtina* cf. *praecedens* Kozlowski, *Ogilviella* sp. nov., *Atrypa* sp. nov., *Atrypina* sp., *Spirigerina* cf. *supramarginalis* (Khalfin), *Meristella* sp., *Nucleospira* sp., *Leptaena* sp., *Cymostrophia* cf. *stephani* (Barrande), *Mutationella* sp., *Rhizophyllum* cf. *enorme* Etheridge, *Heliolites* sp., *Favosites* sp., *Cladochonus* sp., *Cystiphyllum* cf. *australe* Etheridge, *Tryplasma columnare* Etheridge, *Thamnopora* cf. *boloniensis* (Gosselet), *Cladopora gippslandica* (Chapman), *Cheirurus* sp., *Gravicalymene angustior* (Chapman), *Loxonema* sp., *Straparollus* sp., *Hallopora* sp., and *Actinostroma* sp.

Conodonts from the silicified horizon include *Hindeodella* cf. *priscilla* Stauffer, *Spathognathodus steinhornensis remscheidensis* Ziegler, *Spathognathodus steinhornensis steinhornensis* Ziegler, *Spathognathodus inclinatus* cf. *wurmi* Bischoff and Sannemann, *Ozarkodina typica denckmanni* Ziegler, *Ligonodina* cf. *silurica* (Branson and Mehl), *Trichonodella* cf. *inconstans* Walliser, *Hindeodella* cf. *equidentata* Rhodes, *Panderodus acostatus* (Branson and Branson) and *Belodella resima* (Philip).

These conodonts suggest a late Gedinnian or early Siegenian age for the basal limestone of the Mandagery Park Formation. The brachipod assemblage also points to a middle Lower Devonian age for this horizon.

No fossils have been found in the tuffaceous sandstones and lithic sandstones which form the upper part of the formation.

(*c*) *Garra Formation*. Much of the earlier work in the area has been associated with fossils from this formation which comprises the upper part of the Gregra Group. The maps and sections of Strusz (1963, 1965*a*) show the preserved thickness of the formation to vary from about 5,000 feet near Wellington to about 2,000 feet north-east of Manildra.

In the Manildra district limestones of the Garra Formation possibly overlay the Mandagery

Park Formation prior to the exposure of the present erosion surface. Along Boree Creek, 8 miles south-east of Manildra, tuffaceous sandstones of the Mandagery Park Formation pass conformably into the basal limestone of the Gara Formation. Both formations form part of the same calcareous sequence but the former is characterized by abundant acid volcanic debris.

Strusz has shown that the Garra limestones vary in type from massive or well-bedded, to algal, oolitic, and detrital. Closely associated with these limestones, and passing into them both laterally and vertically, are calcareous olive-green shales.

The faunal lists of Joplin and Culey (1938) have been greatly supplemented in recent years by Strusz (1965*a*, 1965*b*, 1966, 1967) but by far the greater part of the palaeontological work has been concerned with corals and most of the numerous brachipods have yet to be described. The corals indicate an Emsian age for most of the limestone (Strusz 1965*b*, 1966).

This long phase of quiet calcareous deposition was ended by the Tabberabberan Orogeny. A complete change of facies followed.

Catombal and Hervey Groups.—These are the uppermost sedimentary deposits in the area apart from occasional Tertiary and Recent consolidated gravels. They consist of reddish sandstones, grits, and conglomerates, and rest unconformably on the Garra Formation to the east of the area and on Siluro-Devonian rhyolites to the west. Stratigraphical and petrological studies of these rocks have been made by Conolly (1963, 1965).

The Upper Devonian sediments exhibit the strong meridional folding and thrust faulting characteristic of the whole region. This suggests that the major part of the tectonic disturbance seen in the earlier rocks was the result of the Lower Carboniferous Kanimblan Orogeny rather than the earlier Bowning and Tabberabberan Orogenies. Furthermore, these sediments overlie granites west of Manildra and thereby suggest a pre-Upper Devonian age for the Manildra and Gumble Granites.

Correlation within the Cowra Trough

The age determinations of the Silurian sediments in the Cowra Trough are largely dependant upon graptolite evidence and it is only where these fossils are absent that wide-spread sedimentation characteristics assume a major role in regional correlation.

The ages of the Silurian formations at Canowindra proposed by Ryall (1965) are based on the determination of a small number of graptolite species but there are sufficient diagnostic forms present to make possible an approximate correlation with the sequences further north (Fig. 1).

The collecting at Spring Creek has been more prolonged and the horizons are known with much greater certainty (Packham and Stevens 1955). The lithologies are different from these at Canowindra but correlation based on graptolite zones shows that the Panuara Formation is equivalent to the Avoca Valley Shales, the Ghost Hill Formation, and part of the Belubula Shale. Packham and Stevens (1955, p. 59) record *Monograptus priodon* and *M. marri* from the lowest part of the Panuara Formation, and *M. bohemicus tenuis*, *M. nilssoni*, and *M. leintwardinensis* from the upper part. Ryall (1965, p. 175–176) records *M. priodon*, *M. spiralis*, and *Retiolites geinitizianus* from the Lower Avoca Valley Shale, *M.* cf. *dubius* from the Upper Avoca Valley Shale, *M. dubius* from the Ghost Hill Formation, and *M.* aff. *bohemicus* from the Belubula Shale.

Further to the west, in the Manildra area the Silurian sediments are thicker and the graptolite horizons more diffuse. Even allowing for this specimens are surprisingly rare. However, sufficient forms have been found to indicate the general ages of the formations and permit correlation with other known sequences. The Greengrove Formation, which contains the graptilites *Rastrites* sp., *Glyptograptus tamariscus*, *Retiolites* sp., and *Monograptus priodon*, appears to be equivalent in age to the lower part of the Panuara Formation at Spring Creek, and the upper horizons of the Millambri Formation and Lower Avoca Valley Shale at Canowindra. The Kurrajong Park Formation, which contains *M.* cf. *testis* and *M.* cf. *flemingi*, and the Mackey's Creek Shale, with *M.* aff. *bohemicus*, appear to be equivalent to the upper part of the Panuara Formation towards the eastern margin of the Trough, and the Upper Avoca Valley Shale, Ghost Hill Formation, and Belubula Shale to the south.

Fossils which have proved particularly common in the Llandoverian rocks of the Cowra Trough include *Glyptograptus tamariscus*, *Monograptus priodon*, *M. spiralis*, *M. marri*, *Rastrites* sp., *Retiolites* sp., and the inarticulate brachiopod *Trimerella* sp. In the overlying Wenlockian deposits the species present usually include *M. testis*, *M. flemingi*, *M. vomerinus*, and *M. dubius*, whilst in the early Ludlovian strata

M. bohemicus has been collected at a dozen or more localities between Wellington and Cowra and is an invaluable index fossil in this area.

Correlation of the early Devonian sediments in the Lachlan Geosyncline is based upon the distribution of brachiopod and coral faunas together with widespread evidence of igneous and tectonic disturbances. The tuffs and greywackes of the Fairhill Formation are rich in rhyolitic and andesitic material, and it seems probable that the periodic influx of this coarse ditritus is related to successive volcanic extrusions nearby. As the Fairhill Formation overlies the *M. bohemicus* horizon, and has a mid-Gedinnian brachiopod fauna in its upper part, the Dulladerry Rhyolite is assigned a late Lludlovian to early Gedinnian age. Further east, in the Four Mile Creek and Spring Creek areas, rhyolite has been recorded overlying the late Silurian Wallace Shale (Sussmilch 1907, Packham and Stevens 1955). This was probably extruded at the same time as the Dulladerry Rhyolite. Younger deposits, rich in volcanic detritus, occur in several parts of the Cowra Trough and also further east, in the Hill End Trough. There could have been a second phase of extrusion during the early Siegenian or alternatively a period of uplift during which the earlier flows of rhyolite were again subjected to rapid erosion.

Deposits of volcanic detritus of probable Siegenian age are widespread in the Lachlan Geosyncline. They include the Mandagery Park Formation in the Cowra Trough and the Merrions' Tuff in the Hill End Trough (Packham, 1958).

The Maradana Shale has been assigned a middle to late Gedinnian age, and the Mandagery Park Formation a Siegenian age, largely on the evidence of the brachiopod and conodont faunas present. The pre-Emsian elements in these faunas include the brachiopods *Dolerorthis*, *Salopina*, *Lissatrypa*, *Proreticularia*, *Atrypina*, and *Anastrophia*. More significantly perhaps, several other genera common in the Emsian deposits of south east Australia are absent from the Manildra assemblages. These include *Nadiastrophia*, *Hysterolites*, *Adolfia*, *Buchanothyris*, *Hipparionyx*, and *Spinella*.

The age of the Garra Formation has been deduced as mainly Emsian by Strusz (1965*b*, 1966, 1967) through an examination of the coral faunas. It may range down into the Siegenian and up into the Eifelian.

The conglomerates, grits, and sandstones of the Catombal Group and Hervey Group represent a complete change of environment. Rapid deposition occurred over a large part of New South Wales and it seems unlikely that there is any significant difference in age between the two Groups in the Manildra area where they outcrop only 12 miles apart. The fossils *Cyrtospirifer disjunctus*, *Lepidodendron australe* and *Holoptychius* sp., suggest an Upper Devonian age for the deposits (Hills 1932, 1935). Browne (1950) tentatively placed these sediments in the Fammenian but more recently Conolly (1965) has assigned a Frasnian age to the lower horizons. However, the fossil evidence available remains very meagre.

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Initial Value Problems in Two-Dimensional Water Wave Theory*

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As it is the custom for the retiring President to devote the last hour, or so, of his term of office in addressing the assembled members and visitors on a topic which is of special interest to him, I would like to attempt, in the time available, a brief survey of one aspect of what is known in Fluid Dynamics as Surface Waves. An idea of the breadth of the topic Surface Waves can be illustrated by referring to the excellent and comprehensive survey of Wehausen and Laitone [16], which occupies some 300 pages. Obviously, then, it is possible only to attempt a description of one small aspect of this field, and the aspect I have chosen is Initial Value Problems in Two-Dimensional Water Wave Theory.

When turning through the pages of the early volumes of the Society's Journal, I was pleased to see that the first paper published was mathematical. The paper [2], by the Honourable Chief Justice Cockle, F.R.S., President of the Queensland Philosophical Society, was on " Non-linear Coresolvents ", and was read to the Society on 7th August, 1867, by Martin Gardiner, Esq., C.E. I was convinced that, due to the Society's long association with Mathematics, I should endeavour to present a mathematical topic as the basis of this address. However, I became somewhat apprehensive on reading further and finding the following remark made by the Rev. W. B. Clarke [1] at the end of the reading of Cockle's paper : " The learned mathematical treatise by the Chief Justice of Queensland, although beyond the appreciation of many, does honour . . . ". However, despite the apprehension, my conviction persisted.

At this stage, then, it might be appropriate to quote remarks which give some idea of the general problem of, and the mathematical difficulties encountered in, surface wave theory. A concise summing up has been given by Wehausen and Laitone ([16], p. 455) when referring to the classification of problems. " Most of the theory of water waves is concerned either with elucidating some general aspects of wave motion or with predicting the behaviour of waves in the presence of some special configuration of interest to oceanographers, hydraulic engineers, or ship designers. Unfortunately, even some of the apparently simplest problems have proved too difficult to solve in their most complete formulation. Approximations have been necessary, and in many cases the problems which have been solved are those which could be solved by the approximate methods in use. An examination of the theory also shows that many of the concepts and definitions are almost inextricably bound up with these methods of approximation, following rather than preceding the making of the approximation.

The nature of the approximations used in treating a particular problem provides a natural way of classifying it. First there are the assumptions concerning the properties of the fluid : viscous or inviscid, compressible or incompressible, surface tension or not. Although assuming the fluid to be inviscid, incompressible, and without surface tension simplifies the equations, they are still not easily manageable, even for the simplest kind of problems. Other approximations of a different nature are required. These are in a sense mathematical approximations. Their physical significance is not in restricting the nature of the fluid but in restricting the character of the waves and the boundary configuration. The kind of mathematical approximation used provides another means of classifying problems . . . There are two principal methods of approximation, . . ., the infinitesimal wave approximation and the shallow-water approximation." Of these approximations, the infinitesimal wave approximation is the one which will be made, at an appropriate stage, in the problem to be considered here.

* Presidential Address delivered before the Royal Society of New South Wales, April 3, 1968.

Equations of Motion

Consider a pair of coordinate axes (x,y) such that the x-axis is horizontal and the y-axis vertically downwards, i.e. in the direction of the gravitational acceleration g. Using the usual convention that the velocity vector has components (u,v) and denoting the pressure by p and the density by ρ, the equations, relevant to the motion of an incompressible, inviscid, irrotational fluid without surface tension in which the only external force is that due to gravity, are

The equation of continuity: $$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0\,; \qquad (1)$$

The equations of motion: $$\left.\begin{aligned}\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}&=-\frac{1}{\rho}\frac{\partial p}{\partial x},\\ \frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}&=g-\frac{1}{\rho}\frac{\partial p}{\partial y};\end{aligned}\right\} \qquad (2)$$

The condition for irrotational motion: $$\frac{\partial u}{\partial y}-\frac{\partial v}{\partial x}=0. \qquad (3)$$

Equation (3) gives rise to a velocity potential $\Phi'(x,y,t)$ such that

$$u=\frac{\partial \Phi'}{\partial x},\quad v=\frac{\partial \Phi'}{\partial y} \qquad (4)$$

which, when substituted in (1), yields Laplace's equation

$$\frac{\partial^2\Phi'}{\partial x^2}+\frac{\partial^2\Phi'}{\partial y^2}=0 \qquad (5)$$

The pressure, obtained from equations (2) and (4), is given by the Bernoulli integral

$$-\frac{p}{\rho}=\frac{\partial \Phi'}{\partial t}+\tfrac{1}{2}(u^2+v^2)-gy+C(t).$$

This last equation may be written

$$-\frac{p}{\rho}=\frac{\partial \varphi}{\partial t}+\tfrac{1}{2}(u^2+v^2)-gy \qquad (6)$$

where the function $C(t)$ has been incorporated with Φ' to form a potential φ. This new potential satisfies equations (4) and (5).

Boundary and Initial Conditions

We will be concerned with the behaviour of the common boundary, $y=f(x,t)$, say, between two immiscible fluids. If one fluid is absent, the boundary surface for the remaining fluid is called a " free surface ". In most cases, the pressure at a free surface is taken to be a constant, e.g. atmospheric pressure. For convenience, in the absence of externally applied pressure distributions this will be assumed to be zero and is used in conjunction with equation (6).

At any bounding surface $F(x,y,t)=0$, whether a free surface or a rigid boundary, we have that

$$\frac{\partial F}{\partial t}+u\frac{\partial F}{\partial x}+v\frac{\partial F}{\partial y}=0.$$

This may be expressed as the condition that the component of the velocity of the fluid normal to the bounding surface must equal the velocity of the bounding surface in the direction of its normal. Special cases of this condition are:

(i) At the free surface $y=f(x,t)$

$$\frac{\partial f}{\partial t}+u\frac{\partial f}{\partial x}-v=0\,; \qquad (7)$$

(ii) For a fluid a finite depth $y=h(x,t)$

$$\frac{\partial h}{\partial t}+u\frac{\partial h}{\partial x}-v=0$$

which becomes for a fluid of uniform depth, i.e. $h=$const

$$v=0\,;$$

(iii) For a fluid bounded by a surface $x=G(y,t)$, say,

$$\frac{\partial G}{\partial t}-u+v\frac{\partial G}{\partial y}=0. \qquad (8)$$

Finally, as we will concern ourselves with the relationship between the behaviour of the free surface subsequent to disturbing a fluid of infinite depth and infinite horizontal extent, initially at rest, by the application of either a known pressure distribution on the free surface ($y=0$) or the known velocity distribution of a vertical and symmetrical wave-making agency acting along $x=0$, we take

$$\left.\begin{aligned} f(x,0)&=0,\\ G(y,0)&=0,\\ \varphi(x,0)&=0. \end{aligned}\right\} \qquad (9)$$

and consider the motion of the fluid to the right of the y-axis ($x>0$). Basically, our problem is to determine, for a fluid which is incompressible, inviscid, irrotational and without surface tension, solutions of Laplace's equation (equation (5)), subject to non-linear boundary conditions on the resulting unknown free surface $y=f(x,t)$ (equation (6)), which satisfy the given initial conditions (equation (9)). The lack of linearity " deprives one, for example, of the mathematical tools of superposition of solutions ; expansion in eigenfunctions or use of Green's functions is not possible " ([16], p. 462).

The Infinitesimal-wave Approximation

The underlying principle of this approximation is to reduce the degree of difficulty of the problem by use of an approximation which replaces the non-linear equations and boundary conditions with linear ones. The original formulation is thus replaced by another for which the solutions are approximate solutions to the original problem under certain circumstances consistent with the geometry of the configuration. (A comprehensive account of the theory of approximations is given by Wehausen and Laitone [16].)

For our purpose it is sufficient to obtain superficially the well-known results of " linearized " (first-order) theory which are applicable to a special class of problems involving small disturbances and which neglect terms of second and higher order. If the motion is such that the elevation of the free surface $y=f\ (x,t)$ is always a small displacement from the initial position $y=0$, we obtain the following initial value problem

$$\frac{\partial^2\varphi}{\partial x^2}+\frac{\partial^2\varphi}{\partial y^2}=0 \qquad (5')$$

$$\frac{\partial\varphi}{\partial t}-gf=-\frac{p}{\rho} \quad \text{on } y=0 \qquad (6')$$

$$\frac{\partial\varphi}{\partial y}=\frac{\partial f}{\partial t} \quad \text{on } y=0 \qquad (7')$$

$$\frac{\partial\varphi}{\partial x}=\frac{\partial G}{\partial t}=U(y,t), \text{ say, on } x=0 \qquad (8')$$

with $f=0$, $G=0$, $\varphi=0$ when $t=0$. ....(9′)

Solution of the Problem

(i) *General Discussion*

The problem posed by equations (5′)–(9′) is now a linear one. Hence, the " pressure " problem appropriate to the boundary condition (6′) and the " wavemaker " problem specified by equation (8′) are independent and can be superimposed. Solutions to these problems have been given,

independently, by Miles [12] and Mackie [10]. For both the pressure and the wavemaker problems, solutions may be obtained by a double transform method using an even Fourier transform in x and a Laplace transform in t [9].

If the respective solutions for $f(x,t)$ to the pressure and wavemaker problems are denoted by $f_1(x,t)$ and $f_2(x,t)$, we have

$$\left.\begin{aligned}\tilde{\bar{f}}_1(k,s)&=\frac{\tilde{\bar{p}}(k,s)}{\rho}\cdot\frac{k}{s^2+kg};\\ \tilde{\bar{f}}_2(k,s)&=-\frac{s}{s^2+kg}\int_0^\infty \tilde{U}(\alpha,s)e^{-k\alpha}d\alpha;\end{aligned}\right\} \qquad \dots\dots\dots\dots (10)$$

where

$$\bar{f}(k,y,t)=\int_0^\infty f(x,y,t)\cos kx\,dx$$

and

$$\tilde{f}(x,y,s)=\int_0^\infty f(x,y,t)e^{-st}\,dt.$$

Taking the inverse Laplace transform of equations (10), we find

$$\bar{f}_1(k,t)=\frac{1}{\rho}\sqrt{\frac{k}{g}}\int_0^t \bar{p}(k,\tau)\sin\sqrt{gk}(t-\tau)d\tau. \qquad \dots\dots\dots\dots (11)$$

$$\left.\begin{aligned}\bar{f}_2(k,t)&=-\int_0^t V(k,\tau)\cos\sqrt{gk}(t-\tau)d\tau.\\ \text{where}\quad V(k,t)&=\int_0^\infty U(\alpha,t)e^{-k\alpha}d\alpha.\end{aligned}\right\} \qquad \dots\dots\dots\dots (12)$$

Thus,

$$\frac{\partial f_2}{\partial t}=\rho g f_1-p(x,t) \qquad \dots\dots\dots\dots (13)$$

provided

$$\bar{p}(k,t)=V(k,t). \qquad \dots\dots\dots\dots (14)$$

By virtue of equations (13) and (14) we may restrict our attention to either the pressure problem or the wavemaker problem. If, for example, we consider in detail the solution of the wavemaker problem appropriate to a given velocity distribution $U(y,t)$ (equations (12)), then, corresponding to the pressure distribution obtained from (14), we find from (13) the solution to that particular pressure problem.

Taking the inverse Fourier transform of (12), we find

$$f_2(x,t)=-\frac{2}{\pi}\int_0^t d\tau\int_0^\infty U(\alpha,\tau)d\alpha\int_0^\infty \cos kx\cos\sqrt{gk}(t-\tau)e^{-k\alpha}dk. \qquad \dots\dots (15)$$

Using the result ([4], p. 15) for $Re\,\beta>0$

$$\int_0^\infty xe^{-\beta x^2}\cos xy\,dx=\frac{1}{2\beta}\;{}_1F_1\left(1;\tfrac{1}{2};-\frac{y^2}{4\beta}\right)$$

where ${}_1F_1(a;c;z)$ is Kummer's confluent hypergeometric function we have, from (15),

$$f_2(x,t)=-\frac{1}{\pi}\int_0^t d\tau\int_0^\infty U(\alpha,\tau)\left\{\frac{1}{\alpha-ix}\;{}_1F_1\left(1;\tfrac{1}{2};\frac{-g(t-\tau)^2}{4(\alpha-ix)}\right)+\frac{1}{\alpha+ix}\;{}_1F_1\left(1;\tfrac{1}{2};\frac{-g(t-\tau)^2}{4(\alpha+ix)}\right)\right\}d\alpha.$$
$$\dots\dots\dots\dots (16)$$

Equation (16) allows the determination of the free surface profile due to a wavemaker of general form $U(y,t)$.

(ii) *The Free Surface Profile as a Power Series in* g

Using the series

$$ {}_1F_1(a,c;z)=\sum_{n=0}^{\infty}\frac{(a)_n}{(c)_n}\cdot\frac{z^n}{n!}, $$

where

$$ (a)_n=\Gamma(a+n)/\Gamma(a), $$

equation (16) becomes

$$ f_2(x,t)=-\frac{1}{\pi}\sum_{n=0}^{\infty}\frac{(-g)^n}{2^{2n}(\frac{1}{2})_n}\int_0^t(t-\tau)^{2n}d\tau\int_0^{\infty}U(\alpha,\tau)\left\{\frac{1}{(\alpha-ix)^{n+1}}+\frac{1}{(\alpha+ix)^{n+1}}\right\}d\alpha. \quad .. (17) $$

Equation (17) agrees with a previous result [9] for the shape of the free surface, as a power series in g, due to a wavemaker $U(y,t)$.

(iii) *The Asymptotic Expansion of* ${}_1F_1(a;c;z)$

For large values of $|z|$ we use the result ([3*a*], p. 278)

$$ {}_1F_1(a;c;z)\sim\frac{\Gamma(c)}{\Gamma(c-a)}\left(\frac{e^{i\pi\varepsilon}}{z}\right)^a\sum_{n=0}^{M}\frac{(a)_n(a-c+1)_n}{n!}(-z)^{-n}+0(|z|^{-a-M-1}) $$
$$ +\frac{\Gamma(c)}{\Gamma(a)}e^z z^{a-c}\sum_{n=0}^{N}\frac{(c-a)_n(1-a)_n}{n!}z^{-n}+0(|e^z z^{a-c-N-1}|) $$

where $\begin{cases}\varepsilon=\ \ 1 \text{ for } \operatorname{Im} z>0\,; & -\pi<\arg z<\pi\,;\quad M,N=0,1,2,\dots\\ \ \ =-1 \text{ for } \operatorname{Im} z<0\end{cases}$ .... (18)

Thus, for large values of $\dfrac{gt^2}{4\sqrt{(\alpha^2+x^2)}}$, we have

$$ \left.\begin{aligned} &\frac{1}{\alpha-ix}\,{}_1F_1\left(1;\tfrac{1}{2};\frac{-gt^2}{4(\alpha-ix)}\right)+\frac{1}{\alpha+ix}\,{}_1F_1\left(1;\tfrac{1}{2};\frac{-gt^2}{4(\alpha+ix)}\right)\\ &\qquad\sim\frac{\sqrt{(\pi gt^2)}}{2}\left\{\frac{1}{(\alpha-ix)}\sqrt{\frac{-1}{\alpha-ix}}\,e^{\frac{-gt^2}{4(\alpha-ix)}}+\frac{1}{\alpha+ix}\sqrt{\frac{-1}{\alpha+ix}}\,e^{\frac{-gt^2}{4(\alpha+ix)}}\right\}\\ &\qquad-\sum_{n=0}^{M}\left(\frac{3}{2}\right)_n\frac{2^{2n}}{g^{n+1}t^{2n+2}}\{(\alpha-ix)^n+(\alpha+ix)^n\}. \end{aligned}\right\} \quad .. (19) $$

Particular Results

(i) A velocity distribution consistent with the approximations of the linearized theory used is

$$ U(y,t)=T(t)\delta(y-y_0) \quad .... (20) $$

where $T(t)$ is a (complex) function of t and $\delta(y)$ is the Dirac delta function. Equation (20) describes a concentrated velocity distribution located at $y=y_0$. The shape of the free surface resulting from such a distribution may be obtained, as a power series in g, by substituting (20) in equation (17). Such substitution yields

$$ \left.\begin{aligned} &f_2(x,t)=-\frac{2}{\pi}\sum_{n=0}^{\infty}\frac{(-g)^n}{(\frac{1}{2})_n.2^{2n}}\cdot\frac{\cos\left[(n+1)\theta\right]}{(x^2+y_0^2)^{\frac{n+1}{2}}}\int_0^t T(\tau)(t-\tau)^{2n}d\tau\\ &\text{where } \theta=\tan^{-1}\left(\frac{x}{y_0}\right). \end{aligned}\right\} \quad .... (21) $$

For an impulsive velocity at $y=y_0$ we have

$$T(t)=\delta(t).$$

Equation (21) then becomes

$$f_2(x,t)=-\frac{2}{\pi}\sum_{n=0}^{\infty}\frac{(-gt^2)^n}{(\frac{1}{2})_n.2^{2n}}\cdot\frac{\cos[(n+1)\theta]}{(x^2+y_0^2)^{\frac{n+1}{2}}}, \quad\ldots\ldots\ldots\ldots\ldots\ldots (22)$$

where $\theta=\tan^{-1}\left(\frac{x}{y_0}\right)$.

In this case we can obtain from equations (16) and (19) the form of the free surface for large values of $\frac{gt^2}{4\sqrt{(x^2+y_0^2)}}$, namely

$$f_2(x,t)\sim\frac{\sqrt{\pi gt}}{(x^2+y_0^2)^{3/4}}\exp\left\{\frac{-gy_0t^2}{4(x^2+y_0^2)}\right\}\sin\left\{\frac{3\theta}{2}-\frac{gxt^2}{4(x^2+y_0^2)}\right\} \quad\ldots\ldots\ldots\ldots\ldots (23)$$

where $\theta=\tan^{-1}\left(\frac{x}{y_0}\right)$. An expression for the remainder may be determined from (19).

The well-known results of the classical Cauchy-Poisson problem obtained by Lamb ([5], [6]) are derived $\left(\text{apart from a factor 2 explained by our adoption of the convention that } \int_0^\infty \delta(\alpha)d\alpha=1\right)$ by substituting $y_0=0$ in equations (22) and (23). These results for the series and asymptotic forms of the free surface are

$$f_2(x,t)=-\frac{2}{\pi x}\sum_{m=0}^{\infty}\frac{(-1)^m}{(\frac{1}{2})_{2m+1}}\left(\frac{gt^2}{4x}\right)^{2m+1} \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots (24)$$

and

$$f_2(x,t)\sim-\sqrt{\frac{gt^2}{2\pi x^3}}\left\{\cos\left(\frac{gt^2}{4x}\right)+\sin\left(\frac{gt^2}{4x}\right)\right\}, \quad\ldots\ldots\ldots\ldots\ldots\ldots (25)$$

respectively.

By virtue of equations (12), (13) and (14), we may also determine from (24) and (25) similar expressions for the free surface profile due to pressure distributions of the form

$$p(x,t)=\delta(t)\delta(x).$$

These are

$$f_1(x,t)=-\frac{t}{\pi\rho x^2}\sum_{m=0}^{\infty}\frac{(-1)^m(2m+1)}{(\frac{1}{2})_{2m+1}}\left(\frac{gt^2}{4x}\right)^{2m} \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots (26)$$

and

$$f_1(x,t)\sim-\frac{t^2}{\rho}\sqrt{\frac{g}{2^3\pi x^5}}\left\{\cos\left(\frac{gt^2}{4x}\right)-\sin\left(\frac{gt^2}{4x}\right)\right\}, \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots (27)$$

respectively.

In fact, the series form of the shape of free surface due to a more general pressure distribution

$$p=T(t)\delta(x)$$

can be obtained by use of equation (13) by first substituting $U(y,t)=T(t)\delta(y)$ in (17). For such a pressure distribution it is found that, for $x>0$,

$$f_1(x,t)=-\frac{1}{\pi\rho x^2}\sum_{n=0}^{\infty}\frac{(-1)^n(2m+1)}{(\frac{1}{2})_{2m+1}}\left(\frac{g}{4x}\right)^{2m}\int_0^t(t-\tau)^{4m+1}T(\tau)d\tau. \quad\ldots. (28)$$

The series involved in the results (24) and (26) may be evaluated using tables computed by Lommel [7].

(ii) If a thin wedge, of angle 2ε, moving with constant speed u along the y-axis plunges into the liquid at rest, then

$$U(y,t)=\varepsilon u\{1-H(y-ut)\}, \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (29)$$

where $H(y-ut)$ is the Heaviside step function.

From (16) we find

$$f_2(x,t)=-\frac{\varepsilon u^2}{\pi}\int_0^t \tau\left[\frac{1}{u(t-\tau)-ix}{}_1F_1\left(1;\frac{3}{2};\frac{-g\tau^2}{4(u(t-\tau)-ix)}\right)+\frac{1}{u(t-\tau)+ix}{}_1F_1\left(1;\frac{3}{2};\frac{-g\tau^2}{4(u(t-\tau)+ix)}\right)\right]d\tau.$$

From the series form of ${}_1F_1\left(1;\frac{3}{2};z\right)$ we have

$$f_2(x,t)=-\frac{\varepsilon u^2}{\pi}\sum_{m=0}^{\infty}\int_0^t \frac{(-1)^m g^m \tau^{2m+1}}{\left(\frac{3}{2}\right)_m 2^{2m}}\left\{\frac{1}{(u(t-\tau)-ix)^{m+1}}+\frac{1}{[u(t-\tau)+ix]^{m+1}}\right\}d\tau,$$

which agrees with an earlier result [8].

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Mesozoic Stratigraphy of the Narrabri-Couradda District

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Abstract—The Mesozoic stratigraphical sequence previously established to the south and south-west, was followed north-east from Narrabri to Couradda, through a narrow zone of outcrop between Tertiary volcanics to the east and Cainozoic alluvium to the west. Upper Jurassic Pilliga Sandstone, and Purlawaugh sediments with mid-Jurassic (J4) microflora, were established overlying Triassic sandstones and conglomerates continuous with Napperby and Digby sediments in areas to the south. No Cretaceous sediments were recognised in outcrop, but they may occur concealed beneath alluvium immediately to the west. Evidence was found of the possible occurrence of Garrawilla lavas beneath Purlawaugh sediments near Couradda, suggesting Mesozoic volcanic activity contemperaneous with widespread eruptions some 50 miles away to the south-east.

Introduction

Results recorded in this paper are the outcome of an investigation of Mesozoic stratigraphy, in an area lying immediately to the north-east of Narrabri. This area, extending from Narrabri to the locality of Couradda, along the Terry Hie Hie road (see Figure 1), lies on the eastern margin of the Great Artesian Basin. It represents a narrow corridor of Mesozoic outcrop, in places only eight miles wide, limited to the east by great thicknesses of Tertiary alkaline volcanics of the Nandewar Mountains, and bounded to the west by Tertiary and Pleistocene alluvium of the North-Western Plains. The Mesozoic outcrops in this corridor are very poor, being largely obscured by local alluvium and low relief. However, they are the only surface outcrops available between the Boggabri-Gunnedah-Coonabarabran region to the south, and the Terry Hie Hie-Gravesend-Coolatai districts to the north.

Mesozoic outcrop stratigraphy, along the north-eastern margin of the Great Artesian Basin in New South Wales, has been established over long distances from Dubbo to Coonabarabran, Gunnedah and Boggabri (Dulhunty, 1965, 1967*a*, and 1967*b* ; Kenny, 1963 ; Offenberg, 1968*a* and 1968*b* ; Offenberg, Rose and Packham, 1968 ; Rasmus, Rose and Rose, 1967 ; Wallis, 1968). In Queensland, it has been established to the east and south-east of the Surat Basin, and followed towards north-eastern areas of New South Wales (Mack, 1963).

The narrow corridor between the Nandewar Range and the North-Western Plains, from Couradda to Narrabri, provided the only opportunity of following Mesozoic outcrop geology from South-Eastern Queensland to Central-Western New South Wales. In view of this, the present investigation was undertaken. Results will, it is believed, assist broad regional correlations in regard to shoreline sedimentation along the eastern and south-eastern margins of the Great Artesian Basin, and aid future studies in stratigraphy and palaeogeography.

Field investigations were confined to studies of Triassic and Jurassic sediments outcropping within the area of the accompanying geological map (Figure 1). Small areas of Permian sediments and volcanics were mapped in the south-eastern corner, but not studied in detail. Similarly, the western margin of well-known Tertiary alkaline volcanics of the Nandewar Mountain was mapped, but not studied, along the eastern side of the area. To the west, along the Narrabri-Moree road and railway, there occur vast areas of Tertiary to Recent alluvium of the Black Soil Plains, possibly overlapping, to the east, marginal Cretaceous sediments to lie on eroded surfaces of Jurassic sandstone.

Concurrently with the present investigation, G. R. Wallis, of the Hydrology Division of the New South Wales Geological Survey, was engaged in regional mapping within the Narrabri district and adjoining areas, and the author had the advantage of discussion and collaboration.

Mesozoic Stratigraphy South of Narrabri

Previous work immediately to the south of Narrabri (Dulhunty, 1967*b*), established a Mesozoic sequence of basal Digby conglomerate underlying thin but variable thicknesses of Napperby sandstone ; both being almost certainly equivalent to Narrabeen sediments of the Sydney Basin. South-west of Boggabri, Triassic beds are separated from overlying Jurassic Purlawaugh sediments by erosional residuals of Garrawilla lavas, but to the north, towards Narrabri, the lavas disappear and Purlawaugh sediments, lying directly upon Triassic, become thinner. Above the Purlawaugh sediments there occur considerable thicknesses of Jurassic Pilliga Sandstone, outcrops of which occupy areas of Pilliga Scrub west of Boggabri and south-west of Narrabri.

Mesozoic Stratigraphy of the Narrabri-Couradda District

Triassic Sediments

Conglomeritic Digby sediments and overlying Napperby sandstones both occur in the Narrabri-Couradda district. Good outcrops of full sections occur above Permian sediments in the south-eastern corner of the district. In the northern half of the district, north of Spring Creek, outcrops of Triassic rocks are almost entirely concealed by Nandewar Volcanics.

To the south of Narrabri, near Boggabri, Napperby and Digby beds appear to thicken and thin, respectively, with increasing distance from their shorelines of deposition (Dulhunty, 1967*b*). In the Narrabri-Couradda district, both sections of the Triassic are somewhat more constant in thickness, as far as can be ascertained from studies of full sections in the south-eastern portion of the district. The Digby conglomerates, lying immediately above Permian sediments, vary from 50 to 75 feet in thickness, and Napperby Beds amount to about 300 feet. There is some evidence of a gradual increase in total thickness of Triassic sediments, from some 350 feet east of Narrabri to over 400 feet north of Spring Creek.

The Digby Beds consist of heavy conglomerates, generally similar in lithology to the thin outcrops between Boggabri and Gunnedah. The Napperby Beds are slightly less calcereous and flaggy, and contain more shaley layers, than in the south. They consist essentially of light-coloured shaley sandstones and gritty shales, interbedded with thick beds of white massive cliff-forming sandstones.

Garrawilla Volcanics

Garrawilla lavas, sills and tuffs, of late Triassic or early Jurassic age (Dulhunty and McDougall, 1966), do not occur between Narrabri and Boggabri, and the present investigation has not revealed any Garrawilla Volcanics in the southern half of the Narrabri-Couradda district. However, there is evidence of their possible reappearance in the northern half of the district, between the valley of Spring Creek and Couradda. On the southern side of Spring Creek valley, near the north-eastern corner of Killarney State Forest, and immediately to the east, there occur outcrops of deeply weathered basic igneous rock at the top of the Triassic and below Purlawaugh sediments, some 60 feet beneath the base of the Pilliga Sandstone. They may well be sills, but in mode of occurrence they clearly resemble outcrops of Garrawilla Volcanics. At the same horizon, on the northern side of Spring Creek valley, weathered basaltic igneous rocks outcrop along very gently sloping hillsides, east from the Narrabri-Couradda road, for about 1·5 miles until obscured by Tertiary Nandewar Volcanics. This occurrence also closely resembles the outcrop of Garrawilla lava, and is represented by a " query outcrop " of Garrawilla Volcanics in the accompanying map, Figure 1.

No further outcrops are available to the north as Mesozoic sediments dip north-west and the surface rises, but several bores put down through Pilliga Sandstone, between Spring Creek and Couradda, have penetrated fine-grained basaltic rocks at depths of 200 to 300 feet. Basalt cuttings were provided by D. S. Blair, from a depth of 220 feet in a bore put down through Pilliga Sandstone on his property " Glencairn ", at the point marked Bore A in Figure 1. This material together with specimens from outcrops along the northern side of Spring Creek valley, were sectioned and examined by T. G. Vallance of the Department of Geology and Geophysics, University of Sydney, who had previously examined Garrawilla and Tertiary basalts from the Coonabarabran-Gunnedah region. Whilst it is not possible, as yet, to distinguish conclusively between the two by petrographic means, Vallance considers that the Couradda sub-surface basalts possess features in common with basalts of the Garrawilla Volcanics, to which they could well belong.

The reappearance of Garrawilla Volcanics in the Mesozoic sequence north of Narrabri, if eventually established, would represent an independent extrusion of lavas in a separate area, but on the same horizon and contemporaneously with the Coonabarabran-Gunnedah eruptions.

Purlawaugh Sediments

Purlawaugh sediments outcropping from beneath Pilliga Sandstone, south of the present area and west of Boggabri, attain a thickness of about 400 feet (Dulhunty, 1967*b*), but become thinner to the north where they extend into the Narrabri-Couradda district. They are characterised by tuffaceous-like sediments, shales, mudstones and lithic sandstones. On weathering they produce highly ferruginous rich red-brown soils containing haematitic and limonitic concretionary nodules, frequently referred to as " red-bed " outcrops. The occurrence of Purlawaugh sediments at the base of the Pilliga Sandstone, is marked by a sudden change in general lithology from overlying coarse quartz-sandstone producing red sandy soil, to underlying shale and lithic sandstone with " red-bed " outcrops.

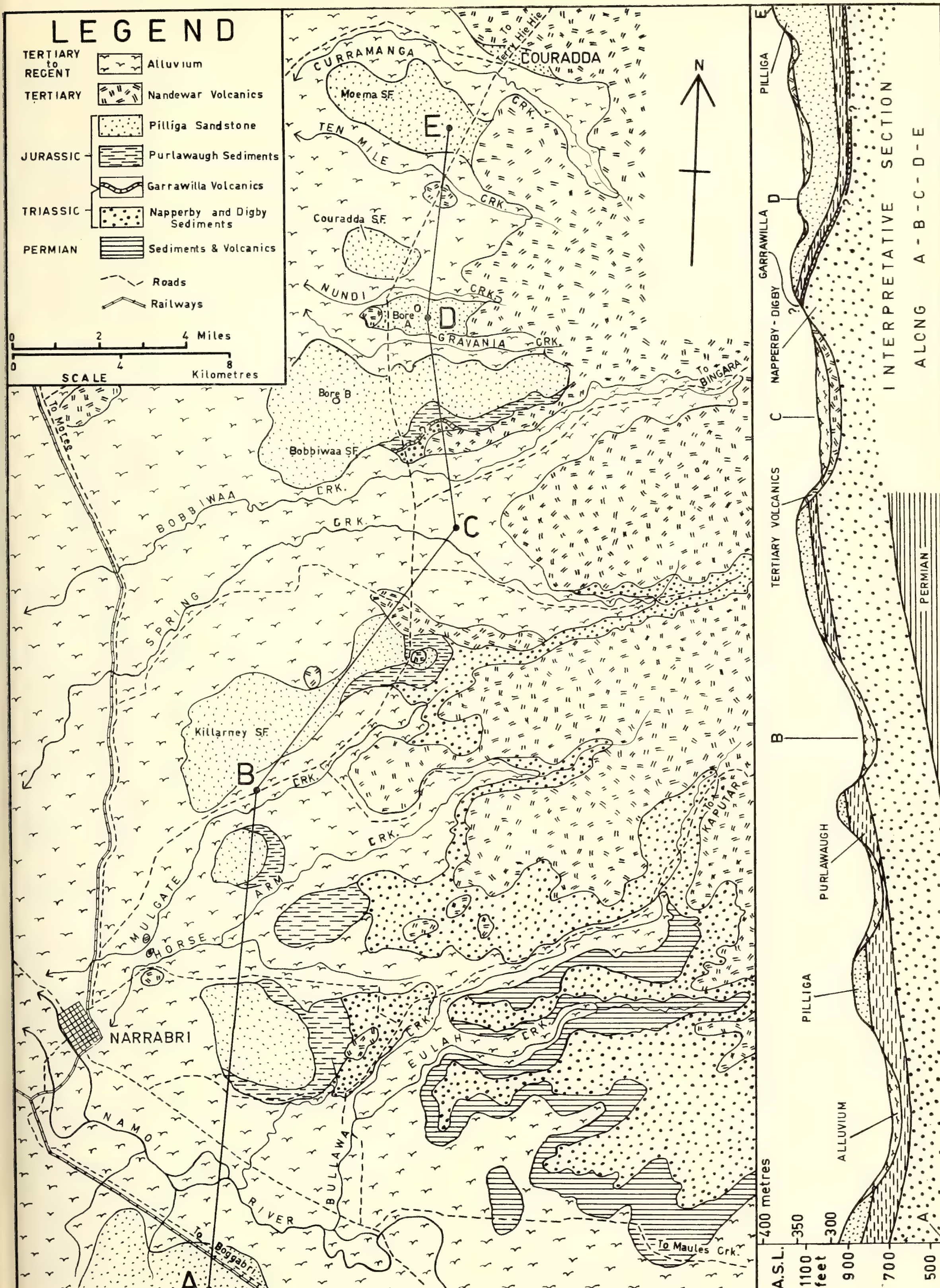

FIG. 1—Geological map of the Narrabri-Couradda District.

In addition to continuity of occurrence from areas to the south, and lithological characterisation, Purlawaugh sediments were established in the Narrabri-Couradda district by palynological evidence. A specimen of shale, provided by B. A. Booker of the New South Wales Forestry Commission, was collected from immediately beneath the Pilliga Sandstone in a bore in Bobbiwaa State Forest (see Figure 1, Bore B) at a depth of between 210 and 240 feet. An examination by R. J. Helby, palynologist of the New South Wales Geological Survey, established in the specimen a J4 microflora of mid-Jurassic age (Evans, 1966), characteristic of upper Purlawaugh sediments to the south and south-west.

Total thickness and detail lithology of the Purlawaugh sediments in the Narrabri-Couradda district, is very difficult to determine, owing to the extensive occurrence of alluvium which obscures outcrops over most of the area. Where surface outcrops occur, direct measurement of thickness is prevented by low relief in almost every instance. Data recorded during the sinking of water bores is of little help, as specimens are necessary for palynological and lithological determinations. However, as a result of consideration of all evidence, the probable thickness of Purlawaugh sediments would appear to vary from some 150 feet near Narrabri to as little as 50 feet at Couradda. The general lithology appears to be very similar to that of Purlawaugh sediments in the Gunnedah-Narrabri-Mullaley region.

Pilliga Sandstone

From the north-eastern corner of the Pilliga Scrub, south of Narrabri, outcrops of Pilliga Sandstone swing easterly into the valley of the Namoi River, as a result of regional dips changing from approximately west-north-west to north-north-west. At this point the river turns west and Narrabri is situated on alluvium on the northern side of the valley. Pilliga Sandstone passes beneath the river, and outcrops in a low timbered rise lying immediately to the east of the Narrabri airfield (see Figure 1).

To the north of Narrabri, the dip of Pilliga Sandstone swings back to approximately west-north-west, and outcrops occur to the north-north-east of Narrabri. They form slightly elevated and timbered rises, including the State Forests of Killarney, Bobbiwaa, Couradda and Moema. All are surrounded by alluvium, and their sandy surfaces and strata dip gently to the west-north-west passing slowly beneath the plains.

The most northerly outcrop of Pilliga Sandstone occurs at Couradda, on the northern side of Curramanga Creek. Beyond this point Tertiary basalt flows pass down from the Nandewar Range and out onto the plains, submerging all outcrops of older rocks for some miles along the Terry Hie Hie road towards Berrygil where widespread outcrops of Mesozoic strata again appear to the north of the Narrabri-Couradda " corridor ".

As far as can be ascertained, the general lithology of the Pilliga Sandstone, so characteristic of outcrops along the eastern and southern sides of the Pilliga Scrub, persist to the north of Narrabri. It is essentially a coarse ferruginous porous sandstone, with irregular developments of conglomerate, sporadic occurrences of pebbles, and occasional interbedded lenses of yellow limonitic and gritty grey-yellow clay shales. The maximum thickness of Pilliga Sandstone is difficult to determine but would appear to be about 250 feet with an eroded upper surface between Narrabri and Couradda, and possibly 400 feet along the western side of the area shown in Figure 1.

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Progressive and Retrogressive Metamorphism in the Tumbarumba-Geehi District, N.S.W.

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ABSTRACT—Regional metamorphism of a group of pelites, psammopelites and psammites in the Tumbarumba-Geehi district has produced a sequence of metamorphic zones centred about foliated granitic rocks. It is considered that the mineral phases originated during four main pulses in the metamorphism. Two progressive metamorphic pulses are evident. These have produced a white mica—opaque oxide assemblage at low grade, whereas biotite, andalusite and cordierite are present at medium to higher grades. Mineral assemblages allow sub-division of the metasediments into four zones, namely, low-grade, biotite, knotted schist and high-grade zones. Two retrogressive metamorphic pulses are characterised by the development of chlorite, or of biotite closer to the metamorphic focus. The distinctive chemistry of the original sediments (high Al, high K : Na ratio) and the presence of graphite in such rocks are believed to have been significant factors in producing the style of metamorphism that is typical of large areas in south-east Australia.

Introduction

The area to be described is underlain by granitic bodies, and by a regionally metamorphosed pelitic—psammitic sequence that forms part of a large belt of Ordovician rocks (Joplin, 1945 ; Hall, 1952) extending throughout north-east Victoria and southern New South Wales. Two of the granitic bodies are associated with the regional metamorphism. These masses, the Corryong and Geehi granites[1] are biotite-rich, occasionally cordierite-bearing, frequently gneissic, and contain numerous sedimentary relics. They resemble the Cooma gneiss (Browne, 1914), Albury gneiss (Joplin, 1947), and the Wantabadgery-Green Hills granites described by Vallance (1953*b*). Other granitic masses (Khancoban, Mannus Creek and Dargals granites) within the area appear to have been emplaced after the period of regional metamorphism. This paper is concerned primarily with aspects of the regional metamorphism. Information pertaining to the granitic masses is to be presented elsewhere.

Nature of the Metasediments

The metasedimentary sequence is similar to that of the Wantabadgery area, where Vallance (1953*a*) noted that the relative proportions of the major rocks are pelites (20%), psammopelites (60%) and psammites (20%). In the Tumbarumba—Geehi district pelites may be somewhat more abundant, carbonaceous pelites in particular being common in the lower grade areas south of Tumbarumba, and south and west of Khancoban (Fig. 2).

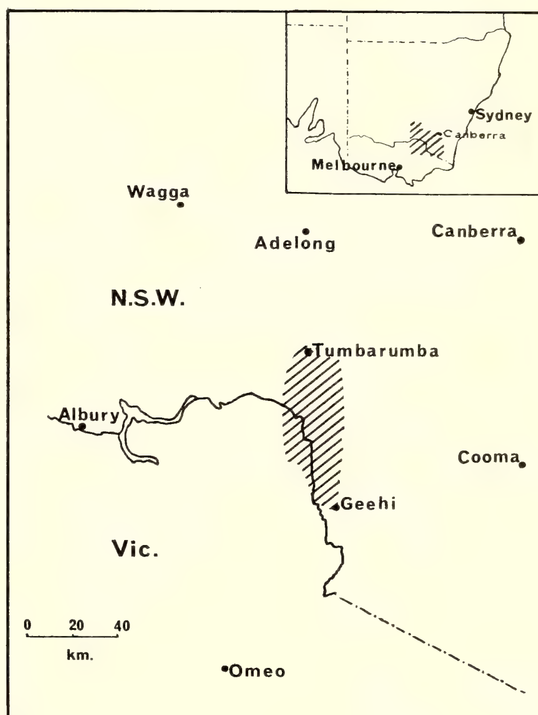

FIG. 1
Locality map, Tumbarumba-Geehi district, N.S.W.

[1] The term " granite " as used in this paper includes all acid plutonic rocks unless otherwise stated.

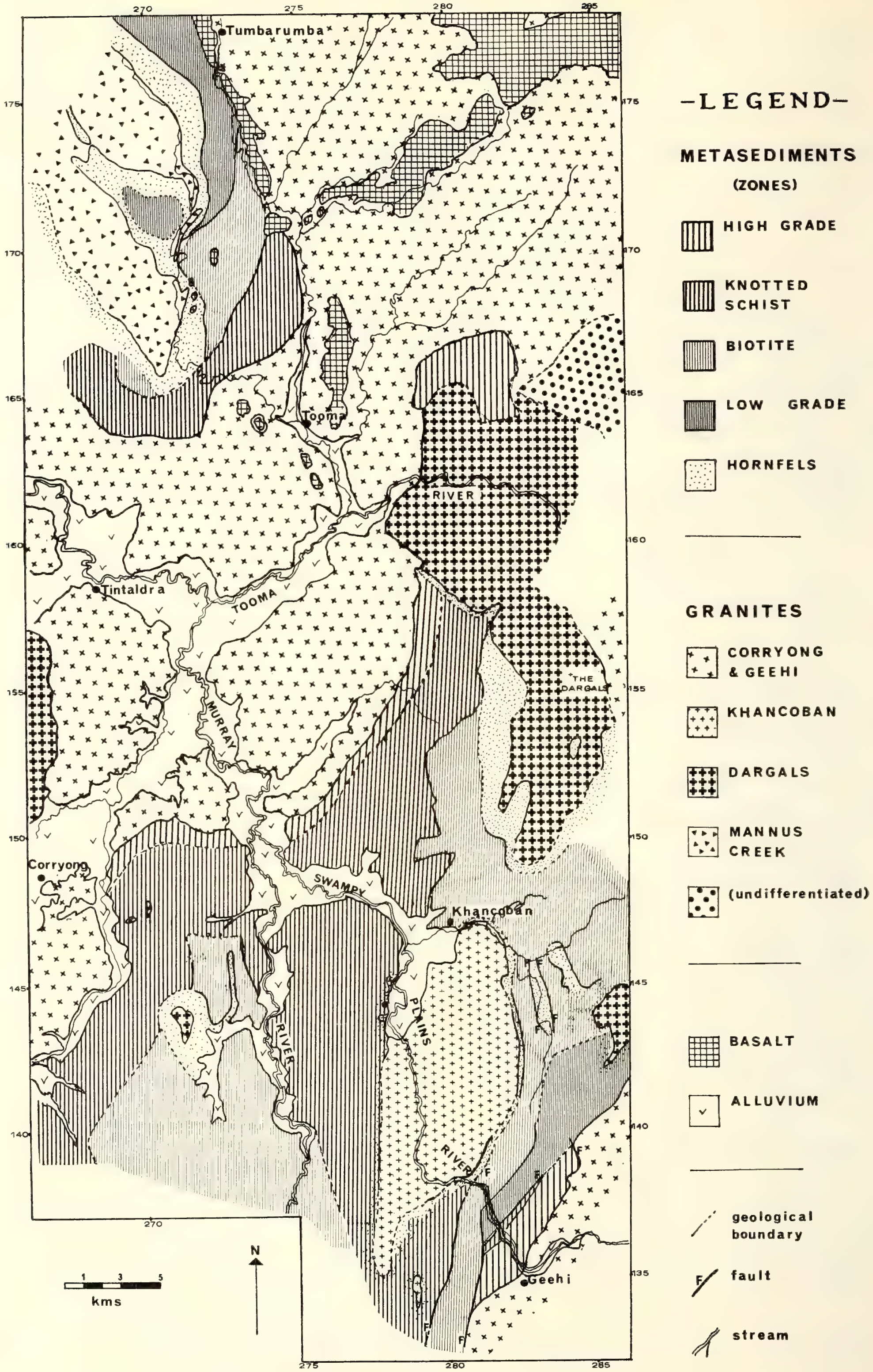

Fig. 2

Geological map of the Tumbarumba-Geehi district, N.S.W., referred to the Snowy Mountains Authority grid.

The metasediments have a north to north-west trend, with local variations. Steep dips ($>65°$) are typical, and some of the folding is almost isoclinal. A steep regional cleavage—at times coincident with, but often at a low angle to bedding and transposing it—is developed in the pelites and psammopelites, as also is a prominent strain-slip cleavage. This latter cleavage deforms the slaty cleavage, and is especially evident in the medium- to higher-grade area. Numerous faults, some of which extend for many kilometres with considerable displacements, post-date the folding and metamorphism.

Chemical Features.—Although only limited data are available for the metasediments of the present area, some 40 analyses have been utilized in a study of the south-east Australian occurrences of similar type. Considerably more analyses are available for the pelites than for the sandier rocks, although such groups display certain chemical similarities. The south-east Australian pelites have a number of distinctive properties (see Joplin 1962). For instance, the unweighted average of Al_2O_3 is 23%, although Pettijohn (1957) notes that the "average" shale contains (*ca*) 15% alumina, with few shales containing more than 20% Al_2O_3. CaO is low ($<1\%$) while the K_2O content and the K_2O/Na_2O ratio are high (Fig. 3). K_2O contents of the psammopelites are usually in excess of 3%, while CaO is less than 0·5%. Chemical variation within the metasediments from south-east Australia is limited (see Fig. 3).

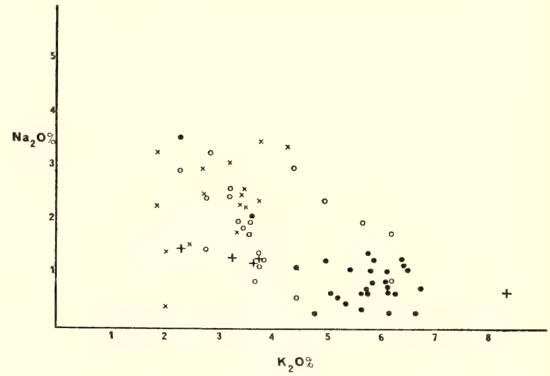

FIG. 4

Na_2O : K_2O plot for pelites used to construct Fig. 3.
● South-east Australian pelites.
X North American pelites.
O Japanese metasediments.
+ Scottish Highlands pelites.

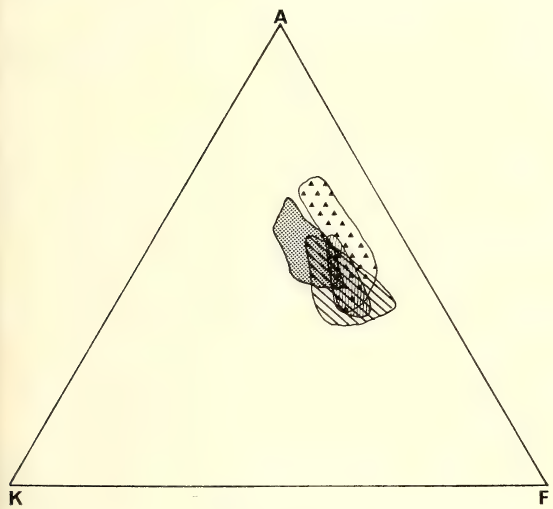

FIG. 3

AKF diagram for pelitic rocks discussed in this paper $A = Al_2O_3 - (Na_2O + K_2O + CaO)$, $K = K_2O$, $F = MgO + MnO + FeO$ (mol.%). Fe_2O_3 has been recalculated as FeO and included in F.

Stippled area : South-east Australian pelites. Analytical data from Howitt (1884, 1886, 1888) ; Tattam (1929) ; Joplin (1942, 1945, 1947) ; Vallance (1953*a*) ; Guy (1964).

Vertical hatching : "Average" analyses of North American pelites. Analytical data from Eckel (1904) ; Clarke (1924) ; Schmitt (1924) ; Nanz (1953) ; Shaw (1956).

Diagonal hatching : Japanese metasediments. Analytical data from Miyashiro (1958) ; Oki (1961).

Triangles : Pelitic rocks from the Scottish Highlands. Analytical data from Higazy (1952) ; Snelling (1957).

Graphical representation of the chemistry of the metasediments is indicated in Figs. 3 and 4. In Fig. 3 a comparison had been drawn with pelites from other areas that have experienced regional metamorphism (viz. the Scottish Highlands and Japan) as well as from areas of North America.

Distribution of the Metamorphic Zones

Regional Zones

Four main zones of regional metamorphism may be recognised and these correspond to the zones of the same name used by Vallance (1953*a*) for the area north of Tumbarumba, viz., low-grade zone (chlorite zone[2]), biotite zone, knotted schist zone (andalusite zone[2]), and high-grade zone (permeation and injection zones[2]). The low-grade zone is defined on the basis of apparent stable co-existence of chlorite and a white mica (muscovite or sericite), although Vallance (1953*a*, p. 99) reports a greenish biotite in parts of this

[2] Terminology of Joplin (1942) for Cooma metamorphics.

zone. The biotite isograd is determined by the first occurrence of a brown biotite, whereas the first development of andalusite or cordierite defines the position of the knotted schist isograd. The biotite and knotted schist zones attain 3 to 5 km. in surface width. The high-grade zone is limited to less than 500 m. in width. This zone is defined on the basis of the stable co-existence of andalusite and potash feldspar, or on the development of sillimanite. Owing to marked retrogressive effects, as well as muscovitisation of rocks within this zone, recognition of critical mineral assemblages was found difficult. Other criteria, viz : (1) development of a second generation of (pink) andalusite and (2) presence of a *lit-par-lit* structure or even a granular (rather than a schistose) texture, were found to be consistent with the above mentioned " critical " minerals. All the regional isogradal surfaces appear to dip steeply.

The regional metamorphic zones are generally centred around or have the maximum grade developed adjacent to the Corryong and Geehi granites (Cooma-type granites). Exceptions occur south of Tumbarumba and north-east of Geehi (near G.R. 285·0—140·7)[3] where there are abrupt changes of grade. In such cases there is evidence of intense shearing in the granites and metamorphics with retrogression of mineral assemblages, particularly knotted schists. The Tumbarumba Creek, Geehi Walls and Bogong Creek faults are the major dislocations to have disrupted the zonal sequence. North-east-trending thrusts occur in the Khancoban district (Cleary *et al.*, 1964) but such dislocations have not produced any anomalous features in the zonal sequence. A minor focus of metamorphic intensity occurs between the Swampy Plains and Murray Rivers (Indi Range), the knotted schists in this region are presumably related to high-grade rocks and possibly granite at depth.

Contact Zones

Adjacent to the Mannus Creek, Dargals and Khancoban granites, contact thermal aureoles are superimposed on the regional zonal sequence. Small granitic masses at Biggera, Victoria and at the Granite Knob have produced significant hornfels zones, some of which are limited by faults. The surface width of the contact zones varies from several hundred metres to over two kilometres. Shallow dipping (40–50°) granite contacts have been established near the wider zones, e.g. at G.R. 268·2—173·6.

[3] Snowy Mountains Authority Grid reference.

Petrography of the Regional Zones Low-Grade Zones

Typical mineral assemblages developed in this zone are :

(*a*) white mica—chlorite—opaque oxides—quartz—albite,

(*b*) white mica—opaque oxides—quartz,

(*c*) white mica — graphite — quartz — (chlorite).

Most of the pelites are very fine grained ($<100\mu$), and are composed of a colourless white mica interspersed with a pale green or yellow chlorite, with distinct preferred orientation of these phases. Chlorite is subordinate in quantity and frequently absent. Although a decidedly minor phase in the pelites, quartz is prominent in granoblastic psammites and psammopelites. The grainsize of the sandy rocks ranges from 0·01 mm. to 0·1 mm., with a broadly bimodal distribution of granual constituents. Opaque oxides are common, while graphite is important in some pelites.

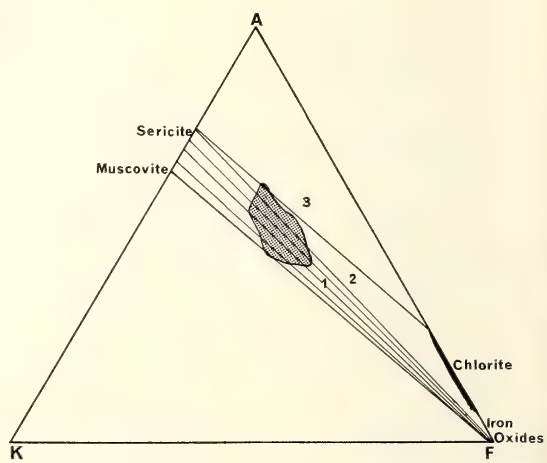

Fig. 5

AKF diagram showing possible mineral assemblages for low-grade zone rocks from south-east Australia. Composition field for pelites is indicated.

Within the low-grade zone, chlorite-rich rocks are not as abundant as, for example, at Cooma, N.S.W. (Joplin, 1942 ; Vallance, 1953*a*, p. 99). Much of the magnesium of the pelites and psammopelites is possibly located in the white micas (?phengites) and opaque oxides. Schaller (1950, p. 408) and Foster (1960) have suggested that such micas have a high Si : Al ratio. This would be consistent with the paucity of quartz in low-grade pelites as compared with higher-grade rocks.

TABLE 1

Colour and Refractive Index Variation in Biotites of the Biotite Zone with Percentages of various Types

Prominent Colour of Z	Low Biotite Zone	Mid Biotite Zone	High Biotite Zone	γ
(*a*) Pelites				
Yellow-greenish yellow	100%	60%	35%	1·649
Olive to mid-brown	0%	40%	65%	1·636
Red brown	0%	0%	0%	—
(*b*) Psammopelites				
Yellow-greenish yellow	50%	50%	40%	1·649
Olive to mid-brown	50%	50%	40%	1·638
Red brown	0%	0%	20%	1·640

In Fig. 5 possible mineral associations are noted for the south-east Australian meta-sediments. The majority of rocks lie in the field of a white mica—iron oxide association. It may be noted that the compositions of pelitic rocks from other terrains, as illustrated in Fig. 3, are slightly removed from the present pelites and such rocks would fall into fields 2 and 3 (Fig. 5) where more chlorite may be expected (*cf.* Barrow, 1912; Tilley, 1925; Oki, 1961).

Biotite Zone

The following mineral assemblages have been observed within this zone:

(*a*) biotite — muscovite — chlorite — (opaques)—(quartz).

(*b*) biotite—muscovite—quartz.

(*c*) biotite — muscovite — opaques — quartz albite—(potash feldspar).

(*d*) (biotite)—muscovite—graphite—quartz.

There is strong preferred growth of micas (in the slaty cleavage) in this zone and some tendency for biotite to form knot-like clots up to 0·25 mm. across in higher grade sections. However, this latter feature rarely interferes with the mapping of the knotted schist isograd (*cf.* Tattam, 1929, p. 10). The micas are the most prominent minerals in the pelites, with biotite dominant. The variation in pleochroic scheme and γ for the bioties are listed in Table 1. Red-brown biotites have not been observed in the pelites (*cf.* psammites) in the Tumbarumba—Geehi district although Vallance (1953*a*) notes that the typical biotite in the upper part of the biotite zone in the area north of Tumbarumba has Z = dark red-brown. The associated white mica is probably muscovite (with $2V_{\alpha} = 33–42°$) but phengitic varieties may be present. Except for the lower grade parts of the zone, chlorite is limited and most blades are associated with retrogressive effects. In some rocks carbonaceous material is occasionally in excess of 60% of the rock, with dark olive-brown biotite as an associated phase.

In some pelitic and psammopelitic rocks subhedral flakes of chlorite are developed oblique to the plane of the schistosity. This mineral, which is only significant in higher-grade sections of the zone, has apparently crystallized after the other constituents of the rock. A discussion of the relation of these chlorites to the regional metamorphism is deferred to p. 190.

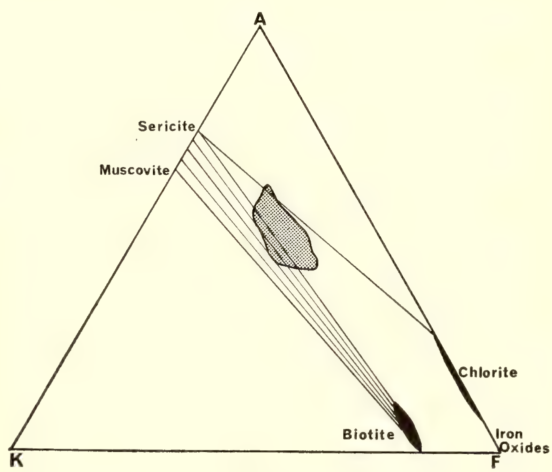

FIG. 6

AKF diagram showing possible mineral assemblages for biotite zone rocks from south-east Australia. Composition field for pelites is indicated.

Many authors (Harker, 1939; Ramberg, 1952 and Yoder, 1959) suggest that a reaction between chlorite and white mica at the biotite isograd produces biotite. It is possible that opaque oxides observed in the Tumbarumba-

TABLE 2

Colour and Refractive Index Variation in Biotites of the Knotted-Schist Zone with Percentages of various Types

Prominent Colour of Z	Low Knotted Schist Zone	Mid Knotted Schist Zone	High Knotted Schist Zone	γ
(*a*) Pelites				
Yellowish brown	60%	35%	10%	1·644
Olive to mid-brown	30%	25%	20%	1·645
Red brown	10%	40%	70%	1·639
(*b*) Psammopelites and Psammites				
Yellowish brown	50%	30%	10%	1·644
Olive to mid-brown	10%	20%	10%	1·636
Red brown	40%	50%	80%	1·642

Geehi are magnesioferrites, so that the reaction at the biotite isograd may have been :

phengite + magnesioferrite → biotite
+ muscovite + quartz + magnetite

Biotite zone assemblages in the Ordovician metasediments of south-east Australia are indicated on Fig. 6. Compositional variation of the white micas has been extended to include " sericitic " varieties. Such micas possibly differ chemically from those of the low-grade zone.

Knotted Schist Zone

Assemblages developed are :

(*a*) biotite—muscovite—quartz—andalusite.

(*b*) biotite—muscovite—quartz—cordierite—opaques.

(*c*) biotite — muscovite — cordierite (?)—andalusite (?)—opaques—(quartz).

(*d*) quartz — biotite — muscovite — opaque —(K-feldspar)—(plagioclase).

(*e*) quartz — muscovite — biotite — graphite —(cordierite)—(andalusite).

Assemblages (a) to (d) have been plotted on an AKF diagram in Fig. 7.

The pelites are distinctly schistose, with a disruption of the foliation by knots of andalusite and cordierite. These minerals increase in amount with metamorphic grade while micas decrease from 70% to 30%. Quartz forms lenticular patches that are elongated in the direction of the slaty cleavage in the pelites, with porphyroblasts of andalusite and cordierite dividing such lenses into two sections (Fig. 8). Albite is present in the psammites although in higher grade sections of the zone a calcic plagioclase (An_{30})[4] occurs.

[4] Compositions of the plagioclases were determined from the extinction angle $X' \wedge (010) \perp [100]$ measured on a universal stage and referred to the low-temperature determination curves of Bordet (1963).

Variations in physical properties of biotites are listed in Table 2, a significant decrease in abundance of yellow-brown types being evident in higher parts of the zone, while the red-brown biotites become prominent. Haematite is often associated with the yellow-brown varieties of biotite. Some chemical data for biotites from this metamorphic belt are available (Guy, 1964).

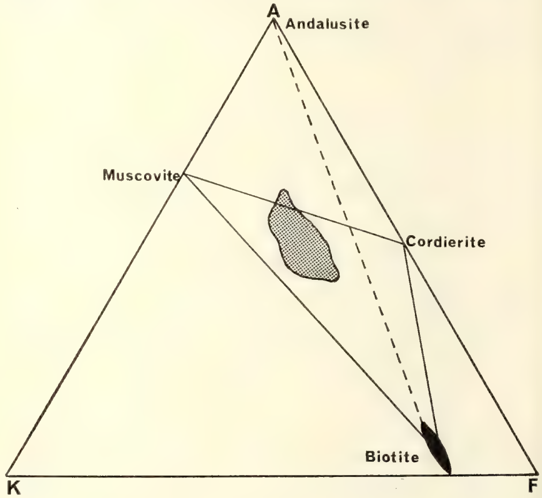

FIG. 7

AKF diagram showing possible mineral assemblages for knotted-schist zone rocks from south-east Australia. After Turner and Verhoogen (1960), for hornblende hornfels facies. Composition field for pelites is indicated. The Mg : (Mg + Fe) ratio is 0·50 for biotites and 0·35 for cordierites (see pp. 188–189).

A mid-brown biotite from knotted schist zone in the present area has the formula :

$(K_{0\cdot80}Na_{0\cdot07}Ca_{0\cdot01})\ (Mg_{0\cdot98}Fe^{2+}_{1\cdot00}Fe^{3+}_{0\cdot20}Al_{0\cdot37}Mn_{0\cdot17}Ti_{0\cdot20})\ (Si_{2\cdot69}Al_{1\cdot31})\ O_{10}\ (OH)_2$

while from rocks of equivalent grade Vallance (1960) records a red-brown biotite with the formula :

$(K_{0\cdot72}Na_{0\cdot09}Ca_{0\cdot02})\ (Mg_{0\cdot94}Fe^{2+}_{1\cdot03}Fe^{3+}_{0\cdot23}Al_{0\cdot41}Mn_{0\cdot08}Ti_{0\cdot15})\ (Si_{2\cdot75}Al_{1\cdot25})\ O_{10}\ (OH)_2$.

Retrogressive alteration of biotite to chlorite is common in the sandier rocks. Muscovite, in large blades (0·4 mm.) with $2V\gamma = 37–40°$, occasionally develops somewhat obliquely to the schistosity.

Knots of andalusite and cordierite are subhedral to anhedral in shape, but in many cases it appears that growth has proceeded during deformation, as oval shapes are common and signs of rotation are evident, small trails of inclusions displaying a sigmodial arrangement. There is a definite tendency for knots in the lower grade sections of the zone to occur in small clusters, as though the knots were either ruptured by deformation during growth or deformation has been such as to affect the nucleation of the knots producing two grains growing in juxtaposition (Fig. 8). Vallance (1953*a*, p. 108) suggested that there has been rotation of the knots into the plane of the schistosity (regional cleavage), but in many rocks of the Tumbarumba-Geehi district the porphyroblasts are aligned in the strain-slip cleavage, suggesting a rotation into the plane of this latter cleavage. Growth of the porphyroblasts probably continued during the formation of the strain-slip cleavage although knots may also have formed prior to the period of influence of this cleavage. Ramsay (1962) considers that arcuate shapes for trails of inclusions is not indicative of rotation during growth, but is the result of flattening (*cf.* Spry, 1963).

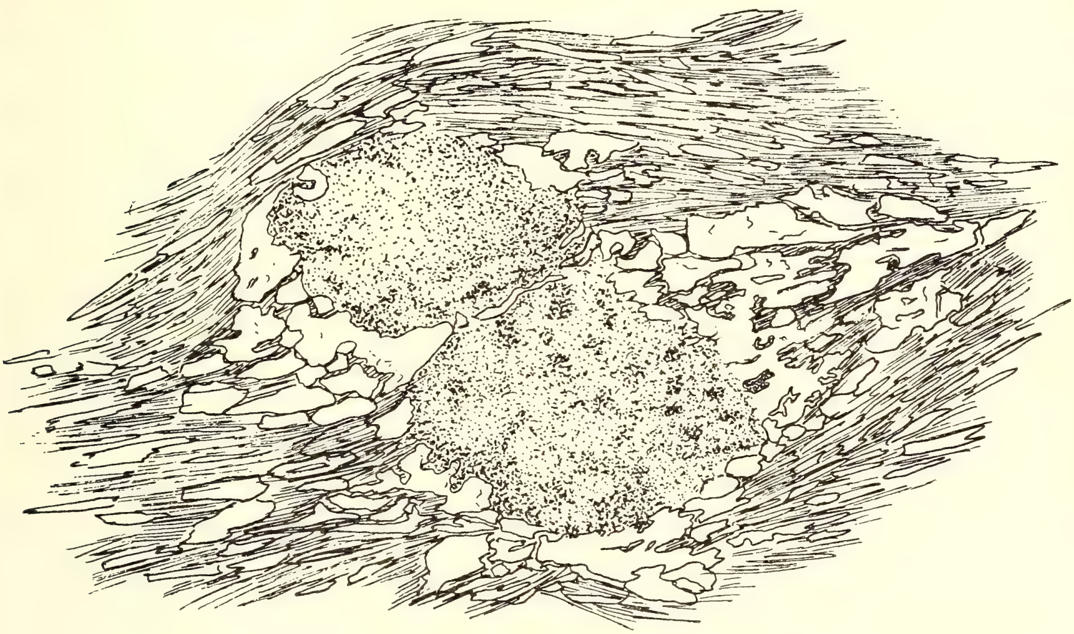

Fig. 8

Two closely associated cordierite grains (stippled) in pelite from knotted-schist zone. Note the presence of granular quartz (clear) within the knotted area.

Most of the knots are rather altered, and only a limited number of fresh andalusites or cordierites have been observed. Cordierite (with sector twinning and $2V\alpha > 65°$) is the more abundant of the two minerals. The cordierite is weakly zoned with an iron-rich core. Using Miyashiro's (1957) distortion index Δ and the refractive index β, two unaltered cordierites were found to have

1. (21639)[5]: $\Delta = 0{\cdot}19$; $\beta = 1{\cdot}548$; approximately 30% Fe (for Mg.).

2. (21715) : $\Delta = 0{\cdot}21$; $\beta = 1{\cdot}553$; approximately 42% Fe.

There is rather extensive pseudomorphous replacement of the knots by large blades of chlorite and white micas. Some chlorite is yellow and nearly isotropic, although most chlorite has X=Y=mid to dark green, and Z = very pale green, with anomalous interference colours and numerous pleochroic haloes. These bladed chlorite pseudomorphs frequently

[5] University of Sydney, Dept. of Geology and Geophysics specimen number.

display mimetic growth after cordierite within the rotated porphyroblasts. Crystallisation in such cases appears to postdate the rotation and hence the strain-slip cleavage. Some chlorite, however, appears to have been deformed by this cleavage and may have developed synchronously with it. In higher grade parts of the zone there is extensive interlaying of chlorite and white mica in the pseudomorphs. As noted above for the biotite zone rocks, chlorite porphyroblasts that are oblique to both the slaty and strain-slip cleavages are developed throughout the knotted schist zone. These presumably postdate formation of minerals previously discussed. They are more common in the higher sections of this zone and attain several millimeters in length, being subhedral to euhedral and somewhat poikilitic, with a small central parting (twinning ?) parallel to their length. The chlorite is a mid-green variety with low birefringence and anomalous blue interference colours. The distribution of the porphyroblasts is not related to the contact thermal metamorphism, their development is apparently a phase of the regional metamorphism.

In knotted schists adjacent to the Corryong granite, muscovite constitutes 50–55% of the rock, as large (2.0 mm.) randomly oriented blades that obliterate the schistosity. Apatite is a common accessory in such rocks.

The reactions leading to the formation of andalusite and cordierite appear to involve silica on the lower grade side (*cf.* Miyashiro, 1958, p. 243). This is suggested by the petrographic evidence of knots commonly existing in quartz-rich lenses and by the tendency of knots to occur in psammopelites at an earlier stage of the progressive metamorphism than in the pelites.

High-grade Zones

Assemblages developed include :

1. quartz — biotite — muscovite — plagioclase (An_{30}).

2. quartz — biotite — muscovite — andalusite—(K-feldspar).

3. quartz — biotite — muscovite — andalusite —cordierite—plagioclase—opaques.

4. quartz — biotite — muscovite — andalusite—sillimanite—opaques.

These have been plotted on an AKF diagram in Fig. 9.

All of the above assemblages display retrogressive affects, such as the presence of chlorite or biotite pseudomorphing knots, and biotite cutting across the regional foliation. Muscovitisation of many rocks within the high-grade zone has obscured textural features, making it difficult to establish stability relationships between the various phases.

The texture of many rocks in the high-grade zone is granoblastic although many of the pelitic rocks are still somewhat schistose. The grainsize is larger than in the knotted schist zone rocks. Quartz grains average 1 mm. in the psammites and 0·2 mm. in the pelites, while knots (now mainly pseudomorphed) attain

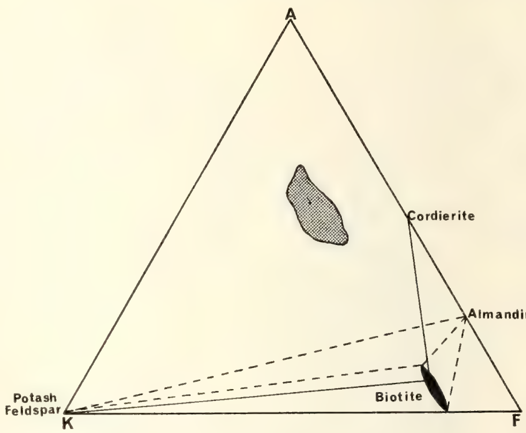

FIG. 9

AKF diagram showing possible mineral assemblages for high-grade zone rocks from south-east Australia. Broken lines after Turner and Verhoogen (1960) for almandine-amphibolite facies. Composition field for pelites is indicated. The high potash content of the metasediments and the decrease of Mg/(Mg + Fe) of of the biotites with increase in grade favour formation of cordierite rather than almandine.

0·8–1·0 mm. in size. Undulose extinction in quartz grains is more evident than in the lower grade rocks while in some examples banding or even cell structure (Wilms and Wood, 1949) is discernible (e.g., 21713). Small amounts of an optically homogeneous alkali feldspar are distributed through the psammopelites and the andalusite-bearing pelites. Fine string perthites are occasionally present, with a tendency for polysynthetic twinning to develop adjacent to the exsolved sodic lamellae. The plagioclase present in this zone is An_{28-30} with $2V\gamma = (ca)80°$.

Biotites typically have X = pale yellow, $Y = Z$ = dark red-brown (γ ranging from 1·640 to 1·645) although in some cases (<10%), dark olive-brown to dark mid-brown varieties ($\gamma = 1{\cdot}640$) exist. The absorption colours of these micas are much deeper than those observed for the previous zones. Pleochroic haloes

around zircon, apatite and (?) monazite are more common than at lower grades. A red-brown biotite from the present area has a formula of:

$(K_{0\cdot86}Na_{0\cdot08}Ca_{0\cdot02})$ $(Mg_{0\cdot93}Fe^{2+}{}_{1\cdot12}Fe^{3+}{}_{0\cdot21}Al_{0\cdot38}$ $Mn_{0\cdot01}Ti_{0\cdot10})$ $(Si_{2\cdot68}Al_{1\cdot32})$ O_{10} $(OH)_2$,

while Vallance (1960) records a red-brown biotite from the Wantabadgery area with the formula:

$(K_{0\cdot74}Na_{0\cdot06}Ca_{0\cdot02})$ $(Mg_{0\cdot92}Fe^{2+}{}_{1\cdot14}Fe^{3+}{}_{0\cdot21}Al_{0\cdot36}$ $Mn_{0\cdot01}Ti_{0\cdot20})$ $(Si_{2\cdot62}Al_{1\cdot38})$ O_{10} $(OH)_2$.

Opaque oxides are associated with biotite, and large blades of muscovite with $2V\alpha = 38\text{–}44°$ are interlayered with biotite. Muscovite is present in several varieties in the high-grade zone, *viz.*, (i) a fine variety pseudomorphing "knots", (ii) large blades developed parallel to the regional foliation and (iii) coarse blades (2-3 mm. long) often in random orientation. Types (ii) and (iii) are not always readily distinguishable from each other. This mineral becomes locally abundant adjacent to the Corryong granite margins and it is possible that there may have been local introduction of potash in these areas.

Most of the knots are altered to white mica and chlorite blades, with little or no evidence of any rotation. Owing to extensive replacement they are not as clearly distinguishable from the mica base as are the knots of the knotted schist zone. Inclusions of quartz and brown biotite are present within the knots.

Small amounts of sillimanite have been observed in this zone, frequently as fine fibrous mats localised in quartz or quartz-rich areas. Some sillimanite appears to have formed from the breakdown of muscovite, but fine needles arranged at 60° to one another are not uncommon within biotite (*cf.* Chinner, 1961, p. 318). Cordierite is present in small, polysynthetically twinned grains that display little or no alteration. A yellow, nearly isotropic chlorite may be associated with this cordierite. Possibly this cordierite is of a generation different from that which existed in the pseudomorphed knots. Unaltered ragged grains of pink andalusite occur as cores to some knots, and also in quartz-rich areas immediately adjacent to the knots. The pink andalusite is quite different both in occurrence and appearance from that observed in the knotted schist zone. Vallance 1953*a*, pp. 111–112) and Joplin (1942, p. 117) have described a similar situation for this mineral in rocks of equivalent grade. Textural relationships suggest that the pink andalusite developed during the time of generation of the strain-slip cleavage.

Some high-grade zone rocks, especially those near the Geehi granite, contain small irregular (up to 1·0 mm.) patches of mica aggregates and chlorite minerals that presumably represent pseudomorphs after cordierite or andalusite (e.g. 21623). These patches are similar to inclusions observed in the Cooma-type granites. The replacement of the knots by green chlorite may be of a slightly later origin than the development of brown biotite inclusions (see p. 191) within the knots. X-ray examination of chlorite pseudomorphs reveals in some examples an interlayering of muscovite with chlorite. Using powder diffraction techniques, the d_{001} and the "b" parameter (Brindley, in Brown 1961) were determined on three chlorite samples indicating compositions of:

(1) (Spec. 21622). Mg_4 Fe Al $(Si_3$ Al) O_{10} $(OH)_8$,

(2) (Spec. 21718). Mg_3 Fe_2 Al $(Si_3$ Al) O_{10} $(OH)_8$,

(3) (Spec. 21719). $Mg_{0\cdot5}$ Fe_4 $Al_{1\cdot5}$ $(Si_{2\cdot5}$ $Al_{1\cdot5})$ O_{10} $(OH)_8$.

(1) and (2) were partly interlayered with muscovite while (3) showed an association with muscovite but no apparent interlayering. The high Fe value for (3) was supported by relatively intense reflections of even $00l$ spacings. Chlorite is dominant over muscovite in these samples.

As in the knotted schist zone, euhedral chlorite porphyroblasts are developed obliquely to the regional cleavage. Such occurrences of this mineral within the high-grade zone are not as common as in the higher grade parts of the knotted schist zone—perhaps because of extensive muscovitisation in the high grade zone. Where present, this chlorite is usually green with a birefringence of 0·015. Euhedral brown biotite porphyroblasts cross-cutting the foliation have also been observed in sections of the high-grade zone, and its restriction to this zone suggests that the chlorite and biotite porphyroblasts are centred around the same metamorphic focus as the main regional influences.

Abundant muscovite and occasional brown tourmaline in higher grade sections of this zone suggest local metasomatism of potash and boron (*cf.* Vallance 1953*a*, p. 117).

Principally because of retrogressive effects, very little critical petrographic evidence is available for the mineralogical reactions that have occurred at the high-grade isograd. It

appears as if there has been initial development of andalusite and cordierite at a knotted-schist grade of metamorphism and the pseudomorphism of these knots by white micas, the potassium for the development of the micas may have been from some external source. The second (pink) andalusite may have been produced by a general breakdown of muscovite with further increase in grade. The limited occurrence of sillimanite in the present area may be related to late muscovitisation obscuring the presence of this mineral, as sillimanite is significant in adjacent parts of the metamorphic belt.

Petrology of the Contact Zones

Rocks discussed in this section are of a polymetamorphic origin ; thermal effects having been superimposed on regional metamorphic assemblages.

Mineral assemblages include :

(1) biotite—cordierite—quartz.

(2) biotite — muscovite — cordierite — quartz — (opaques) — plagioclase (An_{10}—An_{15}).

(3) biotite — muscovite — andalusite — quartz.

(4) biotite — muscovite — quartz — garnet— plagioclase (An_{15}).

Assemblage (4) has been located at only one locality (G. R. 283.6-142.8).

The first signs of thermal metamorphism of the pelites is the incipient development of spots, now composed of white micas, and stained heavily by iron oxides (haematite and limonite). These spots may be mica clusters or represent the commencement of development of andalusite or cordierite (with subsequent pseudomorphism). It is difficult to distinghish these spotted[6] rocks from weakly knotted regional metamorphic rocks.

With increase in grade of contact metamorphism, cordierite and andalusite become more distinct although generally they are retrogressed. Pseudomorphs after andalusite are often recognised by euhedral outlines with (110) and (011) common. Cordierite may be present as unaltered crystals with simple twinning on (110) (see Venketesh, 1954), and also with sector twinning, frequently of complex appearance. Some cordierites displaying such twinning were examined from near the western margin of the Khancoban granite. They have a rather low distortion index ($\triangle$)—$0 \cdot 10$—the subdistortional cordierite of Miyashiro (1957), or intermediate state cordierite of Schreyer and Schairer (1961). The low $\triangle$ value may reflect the rapid crystallisation that would be expected in contact metamorphism. Most biotites are deep red-brown varieties with $\gamma = 1.638 — 1 \cdot 646$, although a few medium brown types have been noted.

The garnet noted in assemblage (4) above, constitutes nearly 7% of the rock (21678) in which it is found, and occurs in relatively large crystals up to $0 \cdot 5$ mm. Slightly pink in appearance, the subhedral garnet has a refractive index of $1 \cdot 818$—probably predominantly of the pyralspite series.

Some of the chlorite porphyroblasts that post-date the slaty and strain-slip cleavages (pp. 190 and 191) and have developed during the regional metamorphism have been observed in the hornfelsed rocks. In such cases the chlorite is replaced by small crystals of red-brown biotite, displaying a preferred orientation, with the z-axis of the biotite perpendicular to the z-axis of the original chlorite. This confirms that the original chlorite porphyroblasts are unrelated to the contact metamorphism.

Summary of Regional Metamorphic History

From the foregoing discussion the variation envisaged between grade of metamorphism, time and space has been schematically displayed in Fig. 10. Conditions postulated for the high-grade, knotted schist, biotite and low-grade zones have been indicated by curves (1) to (4) respectively in Fig. 10, whereas the main thermal impulses have been represented by peaks A, B, C, D, E on these curves. It is considered that each metamorphic zone has successively passed through conditions similar to that postulated for zones of a lower grade, but it is important to note that since tectonic conditions varied with time no zone would have a history identical with that of a lower zone over their common P-T range.

The following sequence of events is postulated for the rocks in the regional metamorphic sequence.

(*a*) A rise in the isogeothermal surfaces in the Earth's crust causing recrystallisation, and

[6] The term " spotted " is used in this paper to qualify thermally metamorphosed rocks in which there has been little or no structural control evident in crystallisation of phases such as cordierite or andalusite.

The term " knotted " is applied to regional metamorphics where growth of the above mentioned phases has been strongly controlled by the stress field.

producing low-grade or biotite zone conditions throughout the area, deformation associated with regional (slaty) cleavage being important in controlling mineral growth at this stage.

(*b*) Continued crystallisation of micas together with the appearance of cordierite and andalusite as stable phases. The growth of these minerals under the influence of deformation associated with slaty cleavage may have been fully realised only in the rocks now designated as high grade. At this stage the present knotted schist zone rocks may not have developed andalusite or cordierite (see Fig. 10, (1) A and (2) A-B).

(*c*) Perhaps a decrease in temperature and/or a slight change in chemical environment such that white micas are produced pseudomorphing knots, this change being evident mainly in the high-grade zone.

(*d*) Increase in metamorphic grade with the formation of sillimanite, pink andalusite and some potash feldspar as well as recrystallisation of micas with biotite forming partly in " knotted areas " from by-products of retrogression of knots (see (*c*)). The strain-slip cleavage may have been important here in controlling or nucleating growth of the pink andalusite. At this stage (or slightly post-dating this, owing to time involved in heat transfer) the knotted schist zone rocks were developing cordierite and andalusite as well as a strain-slip cleavage. This cleavage is not evident in all sections of the knotted schist zone and at times post-dates the development of cordierite and andalusite as well as mica crystallisation in the biotite zone (see Fig. 10, (1) B, (2) A-B, (3) A-B, (4) A-B).

(*e*) A decreased in grade and/or change in chemical environment or sustained lower temperature conditions such that some general retrogression to chlorite and white micas occurred in phases such as cordierite and andalusite, and rarely biotites. This situation may have involved only a variation in P_{H_2O}. In some sections of the area, deformation associated with the strain-slip cleavage may have been of significance and controlled growth of chlorite and white mica (see Fig. 10, (1) C, (3) C-D).

(*f*) A slight increase in grade with the development of subhedral chlorite and very

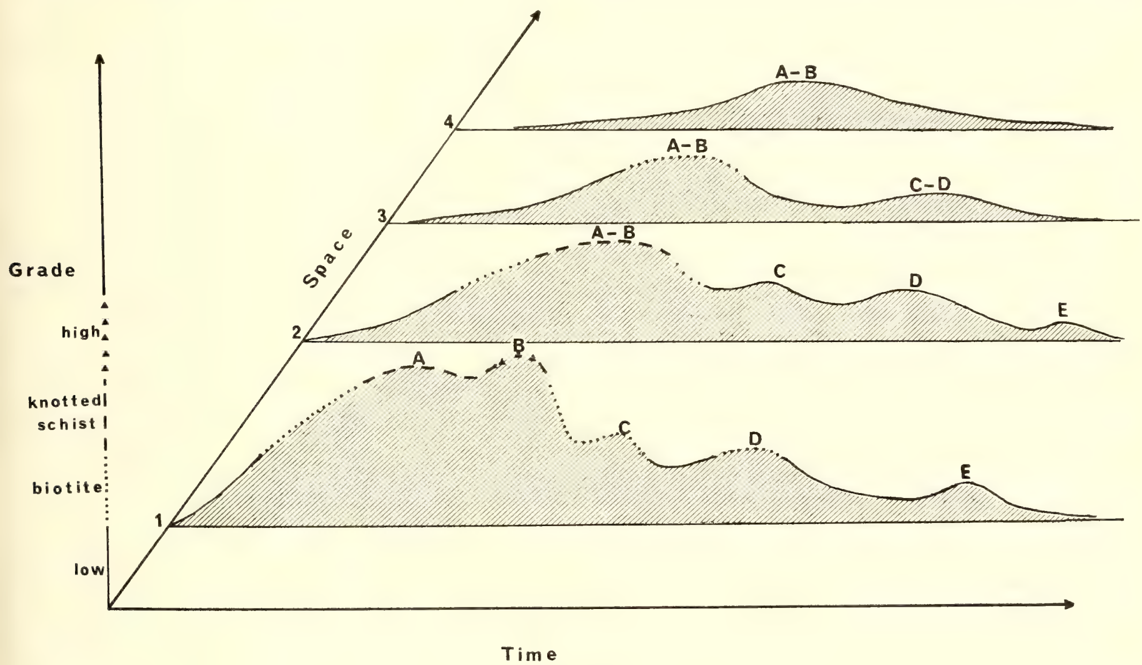

FIG. 10

Schematic diagram for south-east Australian metamorphics showing the relationship between " grade of metamorphism ", " time " (relative to the earliest pulses of metamorphism) and " space " (i.e. distance from the regional metamorphic centre). Curves 1–4 refer to the metamorphic history of the high-grade, knotted schist, biotite and low-grade zones respectively. A, B, C, D represent " pulses " in the regional metamorphism and E represents contact influences of Cooma-type granites during emplacement. See p. 192 for a discussion of this diagram.

occasionally brown biotite porphyroblasts oblique to the cleavages. Most of the influences of the stress field had waned by this stage. Steps (*e*) and (*f*) are clearly definable in the high grade and upper sections of the knotted schist zone, however, in the lower portions of the latter zone these steps are indistinguishable, and in the biotite zone not of significance (see Fig. 10, (1) D, (2) D, (3) C-D).

(*g*) Muscovitisation and, occasionally, tourmalinization of metasediments occurred in the high-grade zone and rarely in the knotted-schist zone. As these processes were effective only adjacent to the margins of the Cooma-type granites, it is likely that potash and boron introduction occurred with, and perhaps preceded emplacement of, the Cooma-type granites (see Fig. 10, (1) E, and (2) E).

Several important considerations arise from the foregoing summary. The major peak of metamorphism is divisible into two main pulses A and B (Fig. 10) in the high-grade zone, and the minor peak is also divisible into two main pulses C and D (Fig. 10), whereas in the lower grade zones these pulses are not clearly definable. Pulse C is not as evident in the high grade zone as in the upper knotted schist zone, owing to the steep thermal gradients in the former zone. The thermal peak in curve (1), Fig. 10, occurred at the same time that the strain-slip cleavage was effective, while this cleavage was coincident and slightly later than the thermal peak in curve (2). As the strain-slip cleavage post-dates the development of minerals in (3), it is possible that this cleavage may be of importance at different times throughout the metasedimentary sequence. A slight time lag may have existed in the thermal pulses between (1) and (4) due to the rate of heat transfer.

Comparison of Metamorphic Styles

Throughout the belts of metamorphic rocks in south-east Australia, there is a definite sequence of mineralogical changes with increase in grade of metamorphism. This style of metamorphism may be referred to as the " Cooma type " (Vallance, 1967) since it was first described from N.S.W. in that region (Joplin, 1942). The metamorphism is regional in extent and characterised by the presence of andalusite and cordierite. It is similar to the Central Abukuma type (Miyashiro, 1958) and not unlike the Buchan type (Read, 1952), although the latter may have almandine, staurolite and even kyanite developed. These various styles of metamorphism (see Miyashiro, 1961) probably reflect differing sets of physical conditions. There are probably significant physical differences between the Cooma and Central Abukuma styles (see Vallance, 1967). Winkler (1965) reports that the Japanese metamorphics have biotite developed as one of the first minerals in response to metamorphism. This is certainly not the case for the south-east Australian rocks, but it is suspected that the lower sections of the greenschist facies are not exposed in the central Abukuma and Ryoke belts (*cf.* Oki, 1961). One of the major differences between south-east Australian and the Japanese sequences is the development of almandine garnet in the Central Abukuma metamorphics (although the mineral is rare in the Ryoke belt). Mineralogical data on biotites from the Khancoban region (Guy, 1964) indicate a decrease in $Mg_5 : Mg_5 + Fe$ with increase in grade of metamorphism. This partitioning of elements may have favoured formation of cordierite rather than an almandine garnet. The higher potash contents of the Australian rocks would have influenced greater development of biotite, with a consequent decrease in available Fe relative to Mg. and thus further limiting the formation of almandine.

Comparison between such sequences is partly complicated by oxidation-reduction conditions in the metasediments. Recently, Chinner (1960) and Miyashiro (1964) amongst others have emphasised the importance of graphite in this regard. Miyashiro suggests that Po_2 is essentially independent of dissociation of water and in graphite-rich rocks the Po_2 may be sufficiently great to effect diffusion of hydrogen into surrounding graphite-free rocks, especially at higher temperatures (i.e. higher grades of metamorphism). However, Chatterjee (1966) has noted that the buffering reactions of both oxygen and hydrogen should be considered in this problem in view of the work of French and Eugster (1965), who indicated that methane may be a significant component in such circumstances under geologically reasonable conditions. The presence of graphite may thus be partly responsible for variations within and between metamorphic sequences, a possible example occurring in the present metamorphic belt being studied. Vallance (1953*a*) describes red-brown biotite as a common phase in biotite-zone rocks at Wantabadgery, whereas in the Tumbarumba-Geehi area such biotites are not common until high in the knotted schist zone. Vallance also notes the paucity of graphite-bearing rocks whereas these are common in the

area described here. There is no evidence from analytical data to suggest that the mobility of oxygen has been a significant process in influencing mineralogical development during metamorphism in south-east Australia. Recalculation of chemical analyses into the form of cationic percentage (Guy, 1964) indicates no systematic variation in associated oxygens in the lower-medium grades of metamorphism. Thus the oxidation conditions appear to be a direct consequence of the availability of graphite. The retrogression of assemblages in the present area has limited the data available on the chemistry of most phases. Although the biotites do not appear so susceptible to retrogression, they may not prove very critical for study at moderate grades, because of apparent influence of graphite on their composition. As many mineralogical reactions are a function of Po_2 (Miyashiro, 1964) particularly those involving elements which may readily exist in more than one oxidation state, the partitioning of elements between various phases (e.g. biotite, cordierite, garnet) may well be related to the presence of graphite.

Some authors (e.g. Winkler, 1965), consider that the style of metamorphism described here is intermediate between contact thermal and regional (Barrovian) metamorphism. The areal extent of the zonal sequence, and the style of deformation within the belt indicates that the metamorphism may indeed be described as "regional", the assemblages having been developed under conditions of non-hydrostatic pressure.

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The Martiniacean Species Occurring at Glendon, New South Wales, the Type Locality of Notospirifer Darwini (Morris)

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ABSTRACT—Specimens of three martiniacean species are known from Glendon, the type locality of *Notospirifer darwini* (Morris). One of these specimens is considered to be conspecific with the lectotype of *N. darwini*, and others are assigned to *Ingelarella* Campbell. Specimens ot the third species are thought to be conspecific with " *Spirifer* " *duodecimcostatus* McCoy which is redescribed. The micro-ornament of each species is highly characteristic and that of the topotype of *Notospirifer darwini* is identical with the micro-ornaments of species currently included in *Notospirifer*. It is different from the micro-ornament of the specimen from Glendon which Waterhouse (1967) considered to be a representative of *Notospirifer darwini*, and which is herein regarded as a possible representative of " *Spirifer* " *duodecimcostatus*.

Introduction

The lectotype of *Notospirifer darwini* (Morris) 1845, the type species of the martiniacean genus *Notospirifer* Harrington (1955) is from the Muree Sandstone at Glendon (David, 1907) in the Sydney Basin. However until recently no well preserved martiniacean specimens had been described from the type locality of this species and two critical characteristics of *Notospirifer darwini* remained incompletely defined. These were the degree of development of the dorsal adminicula and the nature of the micro-ornament of the species.

When Harrington proposed the name *Notospirifer*, he redescribed *Notospirifer darwini* using plaster replicas of the lectotype and of the second specimen which Morris included in the species. He noted that the lectotype had four low plicae on each of the flanks of the valves and that there is quite a distinct median furrow on the fold. Harrington was unable to comment about the characteristics of the interior of the dorsal valve of the lectotype. Regarding the micro-ornament of Morris's specimens he quoted a letter from Dr. Helen Muir-Wood, who stated that the specimens show " obscure traces of spines which must have covered the entire surface. I could not make out any details of the spines themselves ".

Campbell (1959, p. 343) did not consider Morris's two specimens of *Notospirifer darwini* to be conspecific or congeneric. He placed Morris's second specimen (BB 6244) in *Ingelarella* Campbell. Campbell (1959, p. 343) noted that the lectotype of *N. darwini* has a low ventral umbo, a transverse outline and short divergent ventral adminicula which lie outside the plicae bordering the sulcus. He considered that " dorsal adminicula, if present, must be very short ". Contrary to the findings of Muir-Wood (quoted in Harrington, 1955) Campbell concluded that the surface ornament is not shown on either of Morris's specimens, and that the structures described as spine bases are the result of irregular decortication of the shell. Unfortunately at the time of his analysis of the Queensland Permian martiniacean species, Campbell was unable to discover any topotypical specimens of *Notospirifer darwini* (Campbell, 1959, p. 343). However, Campbell (1960, 1961) was able to recognise a number of Queensland species essentially lacking dorsal adminicula and he considered that these species were congeneric with *Notospirifer darwini*. Campbell elected to attribute the micro-ornamental characteristics of the Queensland species to *Notospirifer*, whose micro-ornament was consequently diagnosed as being covered with " deep closely packed subcircular or slightly elongate pits ". All of the Queensland species which Campbell (1960, 1961) placed in *Notospirifer* are characterised by very sho or non-existent dorsal adminicula.

In a paper recently published Waterhouse (1967) figured two well preserved specimens from Glendon. Waterhouse considers one of these specimens (his Pl. 13, Figs. 4–7, 12) to be conspecific with the lectotype of *Notospirifer darwini* and the second (his Pl. 13, Figs. 8–11,

13) he described as *Notospirifer* sp. The former specimen possesses short but quite strong dorsal adminicula and a characteristic spinose micro-ornament. This micro-ornament is markedly different from that of Campbell's Queensland species of *Notospirifer* and indeed it is more like the micro-ornament of Campbell's species of *Ingelarella* and of McCoy's (1847) species "*Spirifer*" *duodecimcostatus* (see later). Waterhouse also notes that if dorsal adminicula are present in the lectotype of *Notospirifer darwini* they must be very short.

A collection made at Glendon in early 1968 yielded a number of martiniacean specimens and these together with Waterhouse's (1967) figured specimens are divisible into three species.

Specimens of one species (Pl. 1, Figs. 8, 10, 11, 12) which is here thought to be conspecific with "*Spirifer*" *duodecimcostatus* McCoy are strongly plicate, have a furrow on the fold, and have a variably distinct median plication in the sulcus. They possess ventral adminicula and short but well developed dorsal adminicula. They have a very distinctive micro-ornament of small cylinder-like spines and narrow radially oriented grooves. Each groove runs forward from the anterior side of a spine and remains entirely superficial. Definitely included in this species is the specimen described by Waterhouse (1967) as *Notospirifer* sp., and doubtfully included is the specimen which Waterhouse (1967) placed in *Notospirifer darwini*.

The second species (Pl. 2, Figs. 5, 6, 7), herein referred to *Ingelarella* sp. cf. *I. angulata* Campbell, comprises specimens which are only gently biconvex and which have gently plicate flanks, a broad fold with a median furrow, and a shallow sulcus which bears two low plicae and a median furrow. There are ventral adminicula and moderately to well developed dorsal adminicula. The micro-ornament of specimens of this species is characterised by subquincuncially arranged grooves and very fine concentric lirae. Each of the grooves arises from the front side of a small C-shaped spine. The spines of this species are broader, lower, and less prominent than those of the first species.

The third martiniacean species at Glendon is represented by one specimen (Pl. 2, Figs. 1, 2, 3). The specimen has gently plicate flanks, a low flattened fold, and strong ventral adminicula. However it seems to lack developed dorsal adminicula. The micro-ornament of the species is very distinctive and is similar to that of the Queensland species which Campbell (1960, 1961) included in *Notospirifer*. The micro-ornament comprises wide, relatively closely spaced grooves which are separated by narrow ridges. At the posterior end of each groove there is a small spinose knob-like protuberance. On the anterior half of the shell of this species the grooves lead antero-internally into small cylindrical pits below the surface of the shell. It is this specimen which is thought to be conspecific with the lectotype of *Notospirifer darwini*.

Mentioned and figured specimens are designated by a number prefixed by several letters which indicate the institution in which the specimen is housed. These are as follows: BB, British Museum (Natural History), London; AMF, Australian Museum, Sydney; CPC, Commonwealth Palaeontological type collection, Bureau of Mineral Resources, Canberra; UQF, Department of Geology, University of Queensland; GSQF, Geological Survey of Queensland. Localitites indexed at the Department of Geology, University of Queensland and at the Geological Survey of Queensland are nominated by a number prefixed by UQL and GSQL respectively. The only other localities referred to are Bureau of Mineral Resources localities. Details of all of the mentioned localities are given in the appendix.

Phylum Brachiopoda Dumeril, 1806
Class Articulata Huxley, 1869
Order Spiriferida Waagen, 1883
Suborder Spiriferidina Waagen, 1883
Superfamily Martiniacea Waggen, 1883

Genus *Notospirifer* Harrington, 1955

Type Species (original designation): *Spirifer darwini* Morris (1845) from the Muree Sandstone in the Sydney Basin, New South Wales.

Diagnosis: Shell of variable size, usually wider than long; cardinal extremities rounded; fold and sulcus present; flanks plicate; there may or may not be a median furrow on the fold and in the sulcus; micro-ornament on the shell comprises closely spaced relatively wide radially elongate grooves separated by narrow ridges; at the posterior end of each groove at the confluence of the ridges around the groove there is a small spinose knob-like protuberance; in three species of *Notospirifer* the micro-ornamental grooves lead antero-internally into shallow cylindrical pits which penetrate below the surface of the shell but never reach the internal surface of the shell; dental plates and adminicula present in ventral valve; dorsal adminicula either absent or very low and very short.

OTHER SPECIES :

Notospirifer minutus Campbell, 1960.
N. hillae Campbell, 1961.
N. hillae var. *plicatus* Campbell, 1961.
N. extensus Campbell, 1961.
N. extensus var. *tweedalei* Campbell, 1961.
N. microstriatus Waterhouse, 1964.
(?) *N. spinosus* Waterhouse, 1965.

COMPARISON : *Notospirifer* generally has a more transverse outline, a lower ventral umbo and less well developed dorsal adminicula than *Ingelarella* Campbell. The micro-ornament of *Notospirifer* is distinguished from that of species of *Ingelarella* by its relatively shorter, wider, more closely spaces grooves. At the posterior end of each groove of the micro-ornament of *Notospirifer* there is a knob-like spinose protuberance. On several species of *Notospirifer* the superficial grooves lead antero-internally into pits below the surface of the shell unlike the micro-ornamental grooves of *Ingelarella.*

Notospirifer darwini (Morris) 1845
Plate 2, Figs. 1, 2, 3, 4, 8, 9

Spirifer Darwini Morris, 1845, p. 279.

?*Spirifer Darwinii* Morris ; Dana, 1849, Pl. 1, Fig. 7*a* (non Fig. 7*b*).

non *Spirifer Darwini* Morris ; de Koninck, 1877, Pl. 10, Figs. 11, 11*a*, 11*b* ; Pl. 11, Figs. 10, 10*a* ; Pl. 16, Figs. 1, 1*a*.

non *Spirifera Darwini* Morris ; Johnston, 1888, Pl. 13, Fig. 4.

non *Martinia* (vel *Martiniopsis*) *Darwini* Morris ; Etheridge, 1892, Pl. 39, Figs. 5–7.

?non *Notospirifer darwini* Morris ; Waterhouse, 1967, Pl. 13, Figs. 4–7, 12.

LECTOTYPE (informally designated by Harrington, 1955, p. 117 and formalised by Campbell, 1959, p. 343) : BB6243 from exposures of the Muree Sandstone at Glendon, New South Wales. The only rock stratigraphic unit outcropping in the vicinity of Glendon Homestead is the Muree Sandstone (David, 1907, pp. 195, 201) which is exposed along the northern bank of the Hunter River just west of the homestead and there is little doubt that this is the type locality for *Notospirifer darwini.* The lectotype has been figured by Harrington (1955, Pl. 23, Figs. 7, 11, 12 and 14), by Campbell (1959, Pl. 56, Fig. 1) and by Waterhouse (1967, Pl. 13, Figs. 1–3).

DIAGNOSIS (based on a plaster replica of the lectotype, on Campbell's (1959, p. 343) remarks about the lectotype, on a comment by Dr. H. Brunton (pers. comm.) of the British Museum (Natural History), and on one other specimen (UQF56154) from the type locality). Shell relatively small and transverse ; moderately biconvex ; 3 or 4 gentle plications occur on each flank of both valves ; sulcus shallow containing two weak plicae and a median furrow ; fold low and broad, bearing a shallow median furrow ; ventral adminicula divergent and about one half as long as ventral muscle field ; dorsal adminicula non-existent or very short, low and divergent ; micro-ornament comprises closely spaced radially oriented grooves separated by narrow ridges ; at posterior end of each groove is a small spine-like protuberance ; on anterior half of shell grooves lead antero-internally into shallow cylindrical pits below the surface of the shell.

DESCRIPTION OF THE SPECIMEN (UQF56154) FROM GLENDON (UQL3262) WHICH IS THOUGHT TO BE CONSPECIFIC WITH THE LECTOTYPE OF *Notospirifer Darwini* : The specimen comprises internal and external moulds of a shell. The shell is slightly wider than long and is moderately biconvex. There are three low rounded plications on each flank of both valves. The sulcus is very shallow and bears a pair of low plicae, one on each side of a shallow median furrow. The fold is broad and low, producing a gently uniplicate commissural trace. Micro-ornament is quite well preserved on the external mould and it is of the type which is characteristic of the Queensland species placed in *Notospirifer* by Campbell (1960, 1961). The micro-ornament comprises closely spaced short radially elongate grooves separated by narrow ridges. At the posterior end of each groove there is a low knob-like protuberance. On the adult growth stages of the shell the superficial grooves lead antero-internally into pits below the surface of the shell. On the external mould the infillings of such pits are circumscribed by a succession of growth lines (Pl. 2, Fig. 9).

In the ventral valve strong ventrally convergent dental plates subtend the margins of the delthyrium and are underlain by short divergent adminicula. The latter plates lie along the posterior sides of the field of muscular attachment and are prolonged as low ridges along the antero-lateral sides of this field. Inner socket ridges and their conjoined crural bases are well developed in the dorsal valve, and in the apex of the valve one of the inner socket ridges is underlain by a very short adminiculum. This adminiculum is one or two millimetres long. Details of the musculature of both valves are obscure.

REMARKS: Of the three martiniacean species occurring at Glendon the one described above is closest to the lectotype of *Notospirifer darwini.* Both the lectotype and the above specimen have similar proportions, a low furrowed fold, similar commissural traces, shallow sulci with two low subplicae, and apparently similar dorsal adminicula. On the topotypical specimen the plications are slightly less well developed. Because of its quite strong divergent dorsal adminicula, its higher fold, its deeper sulcus, its more plicate commissure and its different commissural trace, Waterhouse's (1967, Pl. 13, Figs. 4–7) specimen of *N. darwini* is not thought to be conspecific with the lectotype of *Notospirifer darwini.* The micro-ornamentation on Waterhouse's specimen is quite different from that of the specimen of *Notospirifer darwini* described here and from the micro-ornaments of the species which Campbell placed in *Notospirifer.*

DISTRIBUTION: AMF22792 and AMF24101 from the Gerringong Volcanics at Gerringong, New South Wales are possibly representatives of *Notospirifer darwini.* The former specimen has three low plications on the flanks of the valves, a low ventral umbo, a broad low furrowed fold and a shallow sulcus which bears two barely discernible subplicae and a median furrow. No micro-ornament is present on the specimen but otherwise it agrees very closely with the specimen of *N. darwini* from the type locality. The second specimen from Gerringong (Pl. 2, Fig. 8) has a slightly higher and narrower fold, but there is no sulcal plication and the micro-ornament is most comparable with the micro-ornament of other *Notospirifer* species. A specimen (UQF56155) from the Muree Sandstone at UQL3264 is also closest to *N. darwini.* The specimen is a ventral valve which has a wide flaring sulcus and three low plicae on each flank (Pl. 2, Fig. 4).

Ingelarella sp. cf. I. *angulata* Campbell 1959

Plate 2, Figs. 5, 6, 7, 14, 15

MATERIAL: UQF56156-56160 from the Muree Sandstone at UQL3262, on the northern bank of the Hunter River just west of Glendon Homestead, 6 miles east of Singleton, New South Wales.

DESCRIPTION: The shell is gently biconvex and is wider than long. Four gentle plications are visible on each side of the sulcus and three plicae occur on each flank of the dorsal valve. The sulcus is shallow and bears two low plications, one along each side of a median furrow. Correspondingly there is a broad low dorsal fold which bears a distinct median furrow. The commissure is uniplicate.

The interior of the ventral vale is characterised by an elongate area of muscular attachment bordered on each side by one of the slightly diverging ventral adminicula. The adminicula reach to about the mid-length of the muscle field. Each adminiculum supports a strong low dental plate. The delthyrium is uncovered and the cardinal margin is non-denticulate. In the dorsal valve there is a pair of adminicula of moderate length. In one specimen (UQF-56157) they are about seven millimetres long but in two others (UQF56156, 56158) they reach for between one third and one quarter of the length of the valve. The dorsal adminicula lie along or are medially placed with respect to the first plication on each side of the fold. There is a faint median ridge in the dorsal valve dividing the adductor muscle scars which are arranged as in other species of *Ingelarella* (Campbell, 1959, 1960, 1961).

Micro-ornament of this species comprises narrow radially elongate grooves approximately one millimetre long and 10 to 15 times longer than wide. The grooves are widest posteriorly, and taper in the direction of growth of the shell, and are sub-quincuncially arranged. Each one arises on the anterior concave side of a broad low C-shaped spinose protuberance. The grooves are laterally separated by areas generally wider than themselves and on these areas there are very fine concentric lirae which number about 20 per millimetre.

REMARKS: *Ingelarella* sp. cf. I. *angulata* is distinguished from " *Spirifer* " *duodecimcostatus* McCoy by its lower broader fold, by its smoother less plicate flanks, by the chracteristics of its micro-ornament, and because it possesses two low plicae and a median furrow in its sulcus rather than a sulcal plication. *Notospirifer darwini* lacks the dorsal adminicula of *Ingelarella* sp. cf. *I. angulata* and " *Spirifer* " *duodecimcostatus,* and it possesses a very distinctive micro-oranment.

The Glendon specimens of *Ingelarella* are compared with *Ingelarella angulata* because they are characterised by gently plicate flanks, a shallow sulcus which bears a median furrow bordered by low plications, a low furrowed fold, a uniplicate commissure, and dorsal adminicula of moderate length. The specimens are particularly comparable with topotypical specimens of *I. angulata* (e.g. UQF56161).

"*Spirifer*" *duodecimcostatus* McCoy 1847
Plate 1, Figs. 1–20 ; Plate 2, Figs. 10–13

Spirifer (*Brachythyris*) *duodecimcostata* McCoy, 1847, Pl. 17, Figs. 2, 3.

Notospirifer sp. B ; Dickins, 1966, p. 79.

?*Spirifer duodecimcostata* McCoy ; Dana, 1849, Pl. 2, Figs. 1*a*, 1*b*.

?*Spirifer duodecimcostata* McCoy ; de Koninck, 1877, Pl. 12, Fig. 4.

non *Spirifer duodecimcostata* McCoy ; de Koninck, 1877, Pl. 12, Fig. 4*a*.

non *Spirifera duodecimcostata* McCoy ; Johnston, 1888, Pl. 11, Figs. 2, 4, 9.

non *Spiriferina duodecimcostata* (McCoy) ; Etheridge, 1892, Pl. 44, Fig. 12.

Lectotype (chosen by Waterhouse, 1967, p. 278) : E10644 from the Muree Sandstone in the Sydney Basin, New South Wales. The specimens of "*Spirifer*" *duodecimcostatus* were sent to McCoy by W. B. Clarke from a location which is given as the "sandstone at Muree" by McCoy (1847, p. 320). According to David (1907, p. 200) "the Muree Beds were so called by the late Rev. W. B. Clarke from the typical outcrop in the Muree Quarries at Raymond Terrace". The Muree Quarries are located between one and two hundred yards east of the Muree Golf Club clubhouse on Muree Hill in the eastern part of Raymond Terrace, which is on the Pacific Highway just north of Newcastle. These quarries are though to be the locality from which Clarke's specimens of "*Spirifer*" *duodecimcostatus* were collected. The lectotype was figured by McCoy (1847) in his Plate 17, Figure 2 and a plaster replica of it is figured again in Plate 1, Figures 1 and 2.

Description of the Lectotype (based on a plaster replica of McCoy's specimen) : The specimen is moderately biconvex and is wider than long. It has rounded cardinal extremities and a uniplicate commissure. The ventral umbo is prominent and is the most strongly convex part of the shell. On each flank of the ventral valve there are six strong plications and one very small plica. The sulcus is moderately narrow and deep and it has a distinct median plication. At least five and possibly six plications occur on each flank of the dorsal valve. It is not possible to say whether or not a median furrow was present on the fold because of the poor preservation of this part of the specimen. However the fold is quite narrow and high. No micro-ornamental or internal features of the specimen are visible.

The second of McCoy's specimens (McCoy, 1847, Pl. 17, Fig. 3 ; E10645) of "*Spirifer*" *duodecimcostatus* is a dorsal valve on each flank of which there are five strong plications. On the fold of the specimen there is a distinct median furrow.

A collection made from the Muree Quarries contains a number of specimens similar to and probably conspecific with McCoy's specimens.

Description of 5 Topotypical Specimens (UQF56162-56166) of "*Spirifer*" *duodecimcostamus* McCoy from the Muree Quarries (UQL3264) : The first specimen (UQF56162) comprises internal and external moulds of a dorsal valve. On each flank of the valve there are four strong plications. The fold is broad and bears a distinct median furrow. The sediment in which this and the other specimens from the Muree Quarries are preserved is quite coarsely grained and is very friable. Thus the dorsal cardinalia of this specimen are poorly preserved and cannot be detailed. Similarly the micro-ornament on the external surface of the shell is very obscure. On some parts of the external mould there are impressions of the micro-ornamental features. These suggest that the micro-ornament consisted of narrow radially elongate grooves in quincunx. At the posterior end of some of the grooves there appears to have been a small protuberance. It has not been possible to figure the specimen's micro-ornament but in all essential respects it is identical with the micro-ornaments of similar specimens from Glendon (see below).

The second specimen (UQF56163) is an internal mould of a dorsal valve which has three plicae on each flank and a strong median furrow on the fold. Dorsal adminicula of the specimen are located on the first plication adjacent to the fold. The third specimen (UQF56164), an internal mould of a part of a dorsal valve also shows adminicula about 1/5 as as long as the valve located along the plicae adjacent to the fold. As before the fold is furrowed and there are a number of strong plications on each flank. UQF56165 is also an internal mould of a dorsal valve on which there are four plicae on one flank and five on the other. The fold is quite high and narrow and bears a median furrow. The last specimen (UQF56166) which is thought to be a representative of "*Spirifer*" *duodecimcostatus* is an internal mould of half of a dorsal valve. The fold is high and furrowed and on the right flank there are four plications. Adminicula are quite strongly developed, being located in

the second interplical furrow adjacent to the fold and extending for about one fifth of the length of the valve.

Unfortunately no ventral valves definitely comparable with the lectotype of " *Spirifer* " *duodecimcostatus* were collected from the Muree Quarries.

The dorsal valves described above are inseparable from McCoy's two specimens. On a number of the flanks of the specimens there are one or two fewer plicae than there are on McCoy's specimens but no consistent differences can be detailed. Moreover specimens with a sulcal plication from the Muree Sandstone at Glendon show quite varying degrees of development of the lateral plicae.

Of the three martiniacean species from Glendon which are mentioned in the introduction it is the first one which is here referred to " *Spirifer* " *duodecimcostatus*. The specimens from Glendon are better preserved than the specimens considered to be topotypes of " *Spirifer* " *duodecimcostatus* and for this reason they are completely described. The ten (UQF56167-56176) quite well preserved specimens from Glendon are referred to " *Spirifer* " *duodecimcostatus* because superficially they are inseparable from the lectotype and because their dorsal adminicula and their micro-ornament are virtually identical with the dorsal adminicula and micro-ornament of the topotypes of " *S* ". *duodecimcostatus* described above.

Description of Specimens of " *Spirifer* " *duodecimcostatus* from Glendon : The shell is relatively small and in general it is wider than long. Both valves bear plications and there are from four to six strong plicae on each flank. There is a moderately high fold with a distinct median furrow, and in the sulcus there is a median plication. The areas of the valves are ornamented with grooves and ridges both parallel to and transverse to the direction of growth. The surface of the shell shows several prominent growth lamellae and it bears a micro-ornament of very small cylindrical spines and fine radially elongate grooves. Each of the grooves runs forward from the front of a spine (Pl. 2, Figs. 10–13).

In the ventral valve there are well developed dental plates and adminicula. The latter plates are slightly divergent and reach to about the mid-length of the muscle-field, which is narrow and elongate. There is no thickening in the umbonal cavities or the delthyrial cavity of the ventral valve. Similarly there is no thickening in the posterior part of the dorsal valve. Inner socket ridges are well developed and from them arise the crural bases. Underlying each of the crural bases is a robust adminiculum. The dorsal adminicula are about one fifth as long as the valve and are slightly divergent. They lie below either the first plication or the second lateral furrow on each side of the fold. The cardinal process is small and it comprises a series of longitudinally oriented plates.

Distribution : Transverse specimens characterised by the above features are known from a number of localities throughout eastern Australia. The species occurs in the Muree Sandstone at the Muree Quarries and at Glendon. Specimens from the Gerringong Volcanics (UQF-5614, UQF56177-56182, AMF24073, and AMF-24103) and from the base of the Nowra Sandstone (UQF56183-84) on the South Coast of New South Wales belong to the species. The specimens from the Gerringong Volcanics are quite transverse with four or five plicae on each flank of their valves, a median sulcal plication and the characteristic dorsal adminicula. Adminicula in the dorsal valves of specimens from Gerringong lie in the second furrows away from the fold. A specimen (AMF14123) from Bundanoon Gully, 700 feet below the site of Tooth's old sawmill, 2 miles south of Bundanoon Railway Station is also conspecific. An internal mould of part of a dorsal valve (CPC9908) from the Branxton Formation at HV16 has several plicae on the flanks and dorsal adminicula lying outside the first lateral plicae like other specimens of " *S* ". *duodecimcostatus*. It is probably conspecific. A similar specimen (CPC-9909) is known from HVI*a* in the *Fenestella* zone of the Braxton Formation. This specimen is an internal mould showing the characteristic sulcal plication and widely divergent dorsal adminicula. An internal mould of a ventral valve (UQF56187) whose locality is given as Merlya Pass, Kangaroo Valley, South Coast of New South Wales is characterised by a sulcal plication and four strong plicae on each flank, and is a probable representative of " *S* ". *duodecimcostatus*.

An external mould (UQF49596) of a ventral valve from the Malbina Formation (Member E) is closest to " *Spirifer* " *duodecimcostatus* and a small internal mould (UQF56185) from the same unit may also belong to the species.

In Queensland the species is known from the " Big *Strophalosia* Zone " (UQF56186 from UQL3134) and from locality M416. It also occurs in the base of the Gebbie Formation at GSQLD28. Several specimens (GSQF10553,

11039, 11043–45) from locality GSQLD28 are quite transverse and display the high furrowed fold, a sulcal plication, strongly plicate flanks, and the dorsal adminicula characteristic of " *S* ". *duodecimcostatus.*

GENERIC ASSIGNMENT : " *Spirifer* " *duodecimcostatus* is placed neither in *Notospirifer* nor in *Ingelarella* because of its very distinctive micro-ornament and its sulcal plication. It is one of a number of eastern Australian Permian martiniacean species characterised by these features and when these species are fully understood they will probably necessitate recognition of a new martiniacean genus.

REMARKS : The specimen from Glendon figured by Waterhouse (1967) in Plate 13, Figures 8–11, 13 is definitely a representative of " *Spirifer* " *duodecimcostatus.* The specimen possesses the dorsal adminicula, relatively high furrowed fold, plicate flanks, and distinctive micro-ornament of the species. The affinities of the specimen which Waterhouse (1967, Pl. 13, Figs. 4–7) placed in *Notospirifer darwini* are less readily established. The specimen possesses dorsal adminicula developed to the same extent as the adminicula of the specimens of " *S* ". *duodecimcostatus* from Glendon. It has a relatively high furrowed fold and its micro-ornament is identical with that of specimens of " *S* ". *duodecimcostatus* from Glendon and other localities. However the specimen lacks a distinct sulcal plication and there are faint traces of two very weak sulcal plicae. It seems to have been mainly on the basis of the last mentioned point that Waterhouse placed the specimen in *Notospirifer darwini.* However Dr. H. Brunton (pers. comm.) of the British Museum (Natural History) suggests from an examination of the dorsal valve of the lectotype of *N. darwini* that the valve lacks adminicula but has very short ridges only one or two millimetres long. Moreover the anterior trace of the fold of the lectotype is lower and broader than that of Waterhouse's specimen of *N. darwini.* On the basis of its dorsal adminicula, fold, and micro-ornament, Waterhouse's specimen is thought to be more closely allied to " *Spirifer* " *duodecimcostatus* than to *Notospirifer darwini.* However the specimen is small and whether or not it is conspecific with the former of these species is uncertain.

Summary

Glendon, New South Wales is probably the type locality of *Notospirifer darwini* (Morris) the type species of *Notospirifer* Harrington. A martiniacean specimen from exposures of the Muree Sandstone at Glendon is considered to be a topotype of *Notospirifer darwini.* The micro-ornament on the specimen is particularly characteristic, and all but one of the Queensland martiniacean species included in *Notospirifer* by Campbell (1960, 1961) possess this type of micro-ornament. Waterhouse (1967) has figured a specimen from Glendon which he considers to be a representative of *N. darwini.* However in several respects this specimen is distinguishable from the lectotype of *N. darwini* and from the topotype of this species described herein. The micro-ornament of Waterhouse's specimen is identical with the micro-ornaments of other Glendon specimens which are here considered to be representatives of " *Spirifer* " *duodecimcostatus* McCoy. However although Waterhouse's specimen of *N. darwini* has more features in common with " *Spirifer* " *duodecimcostatus* than it has with the lectotype of *N. darwini*, the specimen is small and there is uncertainty as to whether or not it is conspecific with McCoy's species.

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Appendix

Following are details of the localities referred to in the text.

UQL2788 : Black Head, Gerroa, 2 miles south of Gerringong. Gerringong Volcanics.

UQL3065 : Beach below cliffs immediately east of Shot Tower, Taronga, Hobart, Tasmania. Malbina Formation (Member E).

UQL3098 : In Dry Creek about 1·5 miles from its confluence with Carnarvon Creek. Eddystone 1 : 250,000 map, 148° 17·5′ E., 25° ·5′ S. Peawaddy Formation.

UQL3134 : On track about 1 mile west of Mulgrave Yards west of Parrot Creek, west of Havilah Homestead. Bowen, 1 : 250,000 map, 147° 42′ E., 20° 50′ S. Big *Strophalosia* Zone.

UQL3155 : Road cutting on Pointer Gap road, Milton, South Coast of New South Wales. Base of Nowra Sandstone.

UQL3262 : Northern bank of Hunter River just west of Glendon Homestead, 6 miles east of Singleton, New South Wales. Muree Sandstone.

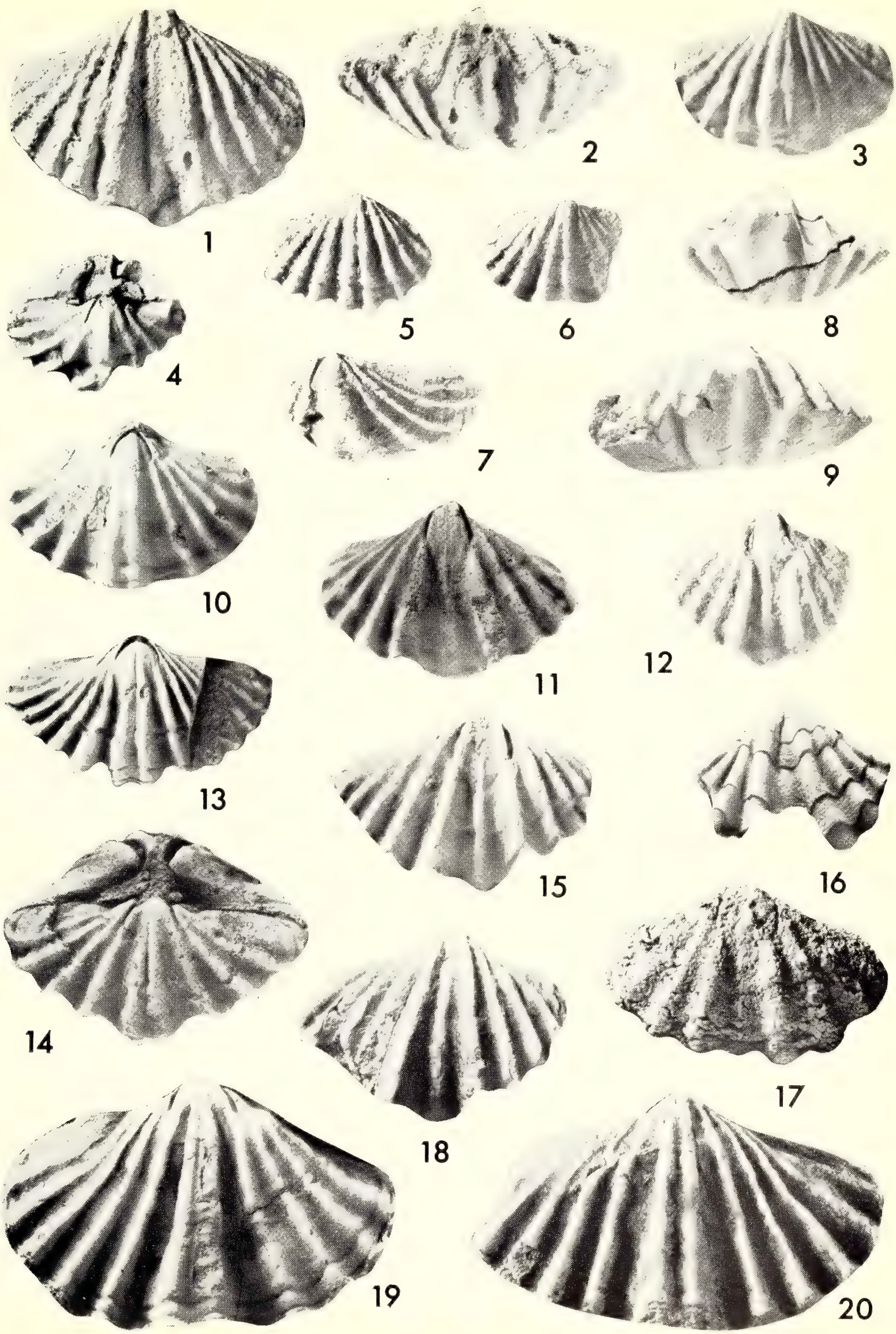
UQL3264 : Small quarries on Muree Hill between 100 and 200 yards east of the Muree Golf Club clubhouse. Muree Hill is in the eastern part of Raymond Terrace on the Pacific Highway just north of Newcastle, New South Wales. Muree Sandstone.

GSQLD28 : The eastern bank of Bowen River near Exmoor Homestead. Base of Gebbie Formation.

HV1*a* : Railway cuttings between 1,100 and 1,600 yards west of Branxton Station. *Fenestella* zone in Branxton Formation.

HV16 : In Redhouse Creek about half a mile east of junction of Dalwood Road with New England Highway, at junction with small tributary. Singleton 1 : 250,000 map, 438 E., 963 N. Branxton Formation.

M416 : Mackay 1 : 250,000 map, 148° 30′ E., 21° 27·75′ S.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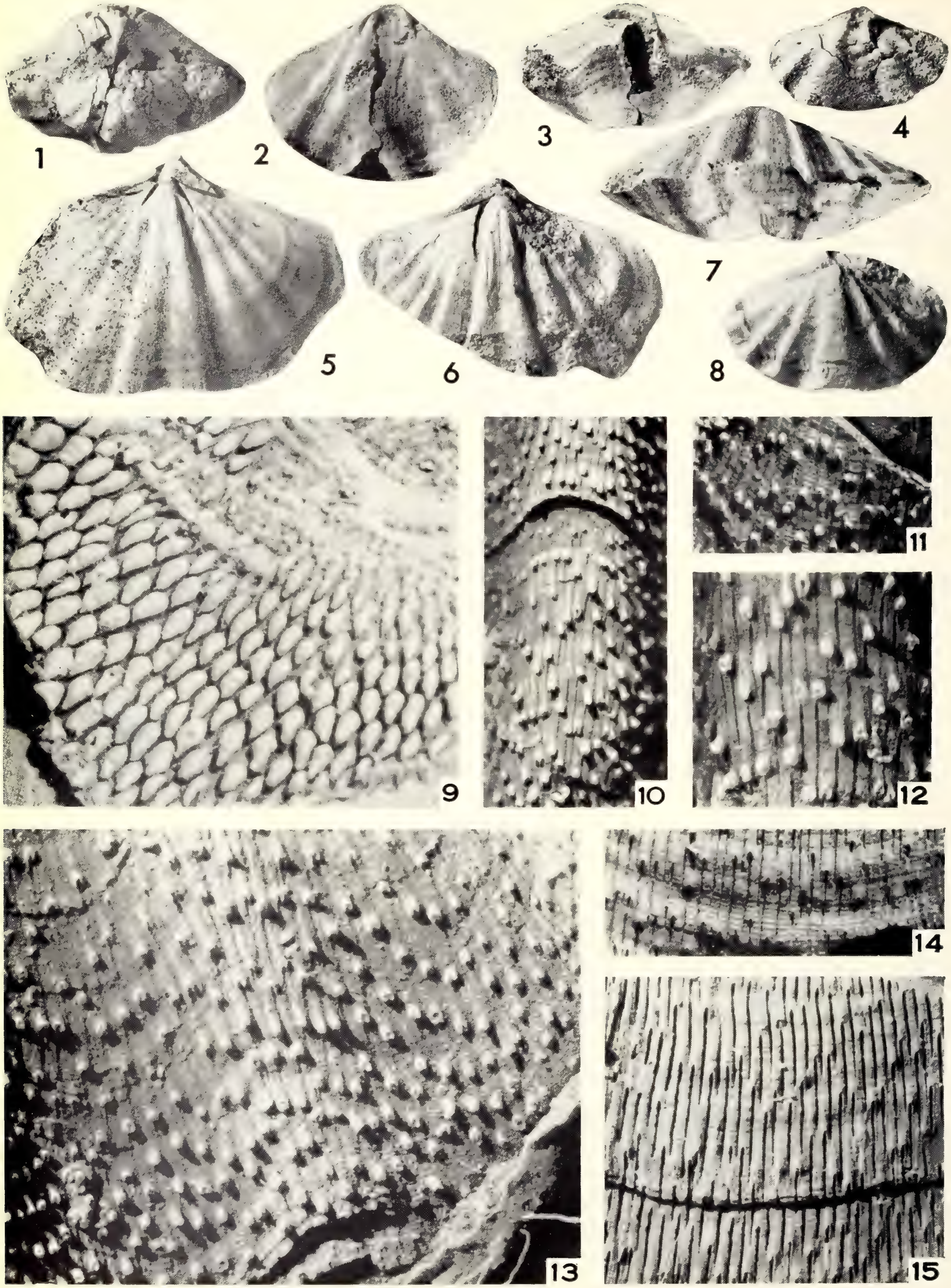
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Explanation of Plates

Plate 1

Figures natural size unless stated.

Figs. 1–2—" *Spirifer* " *duodecimcostatus* McCoy. E10644. Ventral and anterior aspects respectively of a plaster replica (UQF10702) of the holotype.

Fig. 3—" *Spirifer* " *duodecimcostatus* McCoy. E10645. View of plaster replica (UQF10710) of second of McCoy's specimens.

Fig. 4—" *Spirifer* " sp. cf. " *S.*" *duodecimcostatus* McCoy. ×2. UQF56185. Postero-dorsal view of internal mould from the Malbina Formation (Member E) at UQL3065.

Figs. 5–7—" *Spirifer* " *duodecimcostatus* McCoy. UQF56164, UQF56165, and UQF56166 respectively. Internal moulds of three dorsal valves from exposures of the Muree Sandstone in the Muree Quarries (UQL3264).

Figs. 8–9—" *Spirifer* " *duodecimcostatus* McCoy. 8, UQF56168. Anterior view of internal mould from the Muree Sandstone at UQL3262. 9, AMF20473. Anterior view of shell from the Gerringong Volcanics at Gerringong.

Figs. 10–11—" *Spirifer* " *duodecimcostatus* McCoy. UQF56167. Dorsal and ventral aspects of internal mould from the Muree Sandstone at UQL3262.

Fig. 12—" *Spirifer* " sp. cf. " *S.*" *duodecimcostatus* McCoy. UQF56169. Internal mould of ventral valve from the Muree Sandstone at UQL3262.

Fig. 13—" *Spirifer* " *duodecimcostatus* McCoy. AMF14123. Internal mould of dorsal valve from Bundanoon Gully, New South Wales.

Figs. 14–15—" *Spirifer* " *duodecimcostatus* McCoy. 14, GSQF11039. Postero-dorsal view of an internal mould from the base of the Gebbie Formation at GSQLD28. 15, GSQF11044. Internal mould of ventral valve from the same locality as GSQF11039.

Fig. 16—" *Spirifer* " sp. cf. " *S.*" *duodecimcostatus* McCoy. UQF49596. Cast of external mould of ventral valve from the Malbina Formation (Member E) at UQL3065.

Fig. 17—" *Spirifer* " sp. cf. " *S.*" *duodecimcostatus* McCoy. UQF56183. Interna mould of ventral valve from base of Nowra Sandstone at UQL3155.

Figs. 18–20—" *Spirifer* " *duodecimcostatus* McCoy. 18, AMF24103. Ventral aspect of shell from the Gerringong Volcanics at Gerringong. 19, 20, UQF5614, UQF56177 respectively. Internal moulds of dorsal valves from the Gerringong Volcanics at Gerringong.

Plate 2

Figures natural size unless stated.

Figs. 1–3—*Notospirifer darwini* (Morris). UQF56154. Posterior, ventral, and anterior views respectively of an internal mould from the Muree Sandstone at UQL3262.

Fig. 4—*Notospirifer* sp. cf. *N. darwini* (Morris). UQF56155. Ventral valve from Muree Sandstone at UQL3264.

Figs. 5–7—*Ingelarella* sp. cf. *I. angulata* Campbell. 5 and 7, UQF56157. Dorsal and anterior aspects respectively of an internal mould from the Muree Sandstone at UQL3262.

Fig. 8—*Notospirifer* sp. cf. *N. darwini* (Morris). AMF24101. Dorsal valve of specimen from Gerringong Volcanics at Gerringong.

Fig. 9—*Notospirifer darwini* (Morris). ×10. UQF56154. External mould of micro-ornament of shell showing sediment infillings of the pits on the external surface of the shell. Same specimen as in Fig. 1.

Figs. 10–13—" *Spirifer* " *duodecimcostatus* McCoy. 10, ×13. UQF56167. Cast of micro-ornamental spines and grooves. 11, ×13. UQF56168. Cast of micro-ornamental spines, grooves, and concentric lirae. 12, ×25. UQF56167. Portion of micro-ornament in Fig. 10. 13, ×17. UQF56167. Cast of micro-ornamental spines and grooves. The specimens are from the Muree Sandstone at UQL3262.

Figs. 14–15—*Ingelarella* sp. cf. *I. angulata* Campbell. Both ×16. UQF56157. Casts of micro-ornament showing small spine-like protuberances, grooves, and concentric lirae. Same specimen as in Fig. 5.

Journal and Proceedings, Royal Society of New South Wales, Vol. 101, pp. 206–207, 1968

Book Review

The Logic of Special Relativity. By S. J. Prokhovnik.

More than 60 years have elapsed since the appearance of Einstein's epoch-making article in the Annalen der Physik, on the electrodynamics of moving bodies. In the intervening years relativity became an integral part of our physical world picture, penetrating almost all aspects of contemporary physics, from school teaching to the most sophisticated realms of quantum mechanics. Yet even today there is no universally accepted agreement on the exact standing of the theory within the general framework of physics and the correct interpretation of its assertions.

Some regard relativity as an all-embracing theory of space and time which has influenced our ways of thinking about the physical Universe more deeply than almost any other single physical theory in the history of science. Others regard relativity merely as a technical device involving formal manipulations with Lorentz transformations and adding little (if anything at all) to our knowledge of the physical Universe beyond what is laid down in the equations of these transformations. Further down the scale there are those who reject altogether the basic assumptions and experimental foundations of the theory which they regard as wholly inadequate.

The philosophical implications of relativity have been examined by numerous writers from Bergson to Whitehead, but no one has yet attempted a comparative survey of the current physical interpretations and controversies arising from these interpretations. Prokhovnik's "The Logic of Special Relativity" is therefore a welcome and important addition to the voluminous literature on relativity. The title of the book must not be taken too literally ; it is not so much the logic of the theory itself but that of its numerous contributors which is under scrutiny. This is particularly true of the discussion of the notorious clock paradox which appears in some form or other in nearly every chapter of the book.

The author gives a faithful account of the Dingle-McCrea–Builder controversy without committing himself explicitly in either way. He gives a clear exposition of the paradox itself and the arguments surrounding it, making extensive use of a diagrammatic device due to Arzelies. One point on which the exposition is not very clear is the exact meaning of the term " absolute " when applied to time dilatation and similar effects. In a sense any observable effect (such as the mass-energy relation or the relativistic Doppler-effect) is absolute, and it is hardly surprising that relativity does produce such effects—it would be a disaster if it would not.

Paradoxically, the chapter which the reviewer has found most interesting is the one on absolute motion in which the author takes a more definite personal stand and in which the clock paradox is only marginally touched upon. This of course is a chapter to which the author himself has made substantial original contributions and he gives an excellent account of how the theory of (special) relativity looks like if the existence of a distinguished reference frame or state of absolute rest is assumed. For the cosmologist it is hardly necessary to stress the intrinsic interest of such an approach since he is anyhow forced to accept an absolute inertial frame, corresponding to the state of motion of the substratum relative to which the Universe appears to be isotropic.

The " logic of absolute motion " rests on two assumptions :

(*a*) There exists a distinguished frame of reference in which the propagation of energy is isotropic.

(*b*) Movement of a body relative to the distinguished frame is associated with a single effect, the Lorentz-Fitzgerald contraction.

These two postulates and Einstein's conventions on synchronization suffice to deduce the whole fabric of relativistic kinematics. Of course in terms of absolute time, that is time synchronized with respect to the distinguished observer, light propagation becomes unisotropic when the observer is in motion, but the anisotropy effects cancel out in Michelson-Morley type experiments and the net result is the same as in conventional relativity.

There are definite advantages in this approach even for those not interested in cosmology. All relativistic " paradoxical " effects are reduced

to a single easily visualizable physical effect, namely contraction in the direction of motion, and the clock paradox is quite easily resolved, in favour of the conventional (non-Dingle type) solution. Another great advantage is that extension to 3-space, usually a cumbersome and dubious procedure, is achieved here with remarkable ease.

Against these advantages the orthodox relativist might argue that (i) the distinguished state of motion does not show up in local (non-cosmological) observations, that is, in precisely those phenomena to which special relativity normally applies; (ii) there is an artificial anisotropy introduced into the theory which again does not show up in local observations; (iii) the second postulate (B) appears to be quite arbitrary in comparison with the usual Einstein postulates of which of course it is a consequence.

The first two objections are to some extent removed in the last chapter where yet another postulate (McCrea's light-hypothesis) is introduced in order to meet cosmological requirements. On the cosmological scale the distinguished frame *does* show up in concrete physical effects, but this is only to be expected since the extended system is equivalent to a certain general relativistic model.

The third objection cannot really be dispelled on physical grounds alone since the answers given by the new approach are identical (locally) with those given by orthodox relativity. It is the individual's outlook towards laws of nature in general which will ultimately determine his stand towards Prokhovnik's case for the ether. Perhaps the greatest single merit of this book is that it brings home more vividly than any previous writing the fact that relativity is perfectly consistent with an ether-like hypothesis and that our acceptance or rejection of such a hypothesis is a matter of taste rather than of substance.

G. Szekeres.

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JOURNAL AND PROCEEDINGS

OF THE

ROYAL SOCIETY OF NEW SOUTH WALES

VOLUME 102

PARTS 1 - 4

1968-69

PUBLISHED BY THE SOCIETY,
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VOLUME 102 1969 PART I

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ISSUED OCTOBER 13, 1969

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Journal and Proceedings, Royal Society of New South Wales, Vol. 102, pp. 1–4, 1969

Geology of the Talbragar Fossil Fish Bed Area

J. A. Dulhunty and J. Eadie

Abstract—Chert containing Jurassic plant and fish fossils occurs as loose blocks floating in soil derived by weathering from Jurassic Purlawaugh sediments overlain by remnants of Pilliga sandstone and underlain by Triassic Narrabeen sandstone. From field investigations it is concluded that the loose blocks of chert represent displaced erosional remnants, and all that is left, of an isolated lake-bed deposit now almost completely removed by erosion. The chert bed appears to have accumulated over a relatively short period of time, probably less than 250 years, and possibly as little as several seasons.

Introduction

The widely known occurrence of Jurassic fish fossils, generally referred to as the "Talbragar Fossil Fish Bed", is situated some 20 miles north-east from Gulgong, on Farr's Hill, in Portion 14, Parish of Bligh. Hard cherty shale containing Jurassic plant and fish fossils (Woodward, 1895; Wade, 1942) occurs as loose blocks floating in soil derived from weathering of soft argillaceous sedimentary rocks. The occurrence was originally described (David and Pittman, 1895) as Jurassic sediments infilling an erosion hollow in Triassic sandstone. Later it was established (Dulhunty, 1938) that the Fish Bed Chert was associated with an outlier of Jurassic sediments, then described as Munmurra sandstone and Comiala shales, but now known to be equivalent to the Pilliga sandstone and Purlawaugh Formation, outcropping over wide areas to the north (Offenberg, 1968; Offenberg, Rose and Packham, 1968). It was also suggested by Dulhunty that the chert may have been deposited in an erosion hollow in the Jurassic Pilliga sandstone. However, details of occurrence and relations to associated Jurassic sediments remained uncertain as all outcrops were largely concealed by deep soil on gently sloping hillsides.

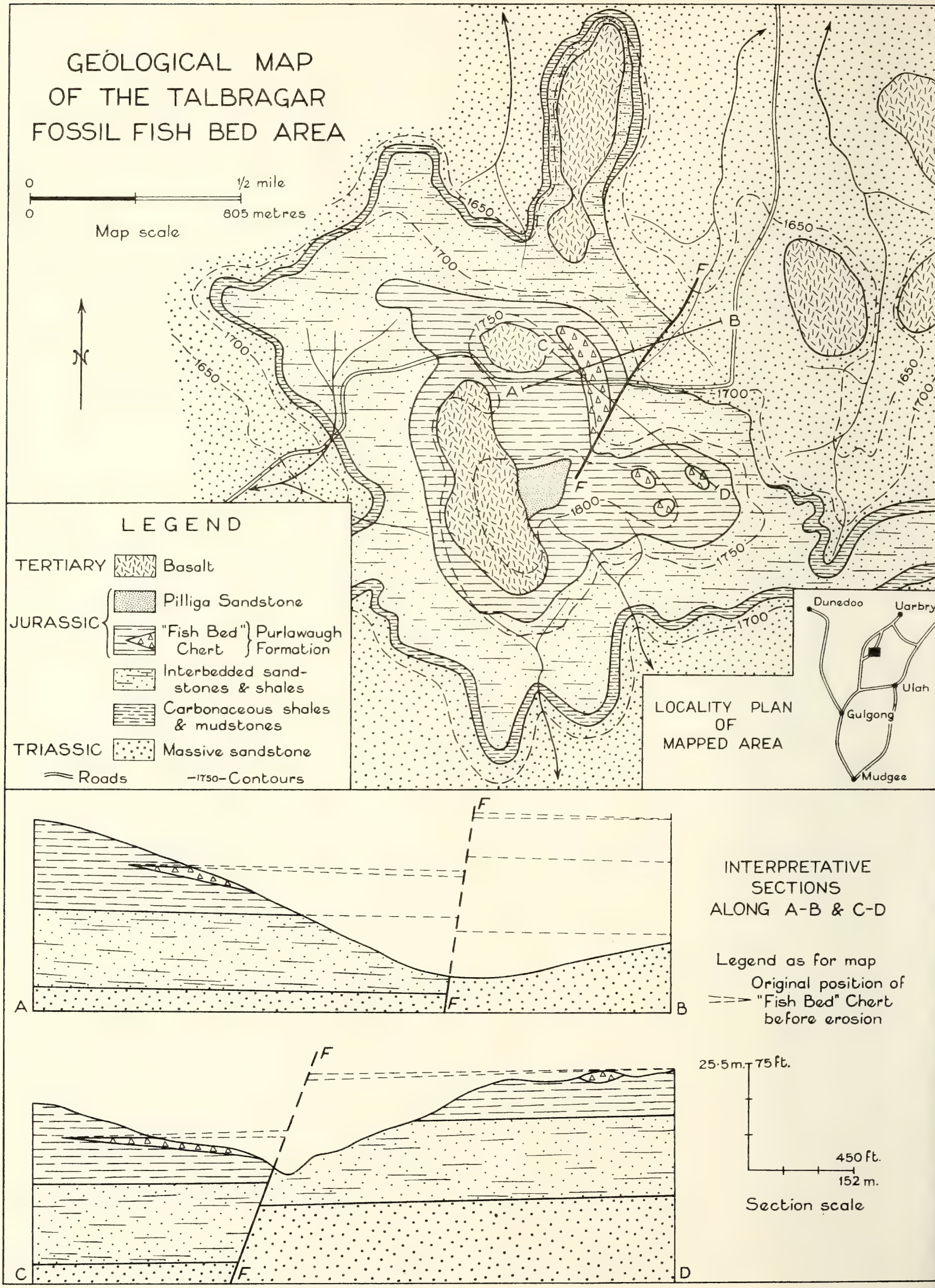
Recently, a more exact understanding of the geology of occurrence of the Fish Bed Chert became necessary in connection with biological studies of the fossil fish, and an investigation, results of which are recorded in this paper, was undertaken by the present authors.

General Stratigraphy

The general stratigraphical sequence, in the vicinity of Farr's Hill, is indicated in the legend and map of Fig. 1. The oldest sedimentary rocks outcropping in the area are Triassic sandstones. They are continuous across the Main Divide, with sandstones of the Narrabeen Group to the east and north-east in the Goulburn River-Rylstone-Capertee region.

Younger Mesozoic sediments, lying upon the Triassic sandstone, have been extensively dissected and removed by erosion in the Farr's Hill area, and occur only as ridge-cappings and outliers. The lowest is a bed of blue-grey carbonaceous shale about 20 feet thick. It forms a well-marked horizon throughout most of the area, but is absent in the vicinity of the Fish Bed Chert, as shown in Fig. 1, having been removed by erosion immediately following deposition. The blue-grey shale is overlain by about 60 feet of alternating sandstone and shaley beds with predominating grey-white and yellow-grey coloration. Next in sequence come some 80 feet of ferruginous shales, mudstones and lithic sandstones, which produce rich red and brown soils with haematitic and limonitic concretions, and with which the Fish Bed Chert is associated. These ferruginous sediments have been traced north by means of outliers to the vicinity of Uarbry, where they become continuous with sediments of the Jurassic Purlawaugh formation in the Coolah-Binnaway-Coonabarabran region to the north-west. Above the Purlawaugh sediments, on top of Farr's Hill, there occur remnants of a coarse pebbly ferruginous quartz sandstone which has been correlated with the Pilliga sandstone overlying Purlawaugh sediments to the north.

Of the foregoing stratigraphical sequence the Pilliga sandstone and Purlawaugh sediments are Jurassic in age, and the basal Narrabeen Group sandstones are Triassic but, as indicated in Fig. 1, the exact ages of the two intervening series of beds have not yet been established.


GEOLOGICAL MAP
OF THE TALBRAGAR
FOSSIL FISH BED AREA
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N
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1750
1800
A
B
C
D
F
LEGEND
TERTIARY Basalt
JURASSIC Pilliga Sandstone
"Fish Bed" Chert } Purlawaugh Formation
Interbedded sandstones & shales
Carbonaceous shales & mudstones
TRIASSIC Massive sandstone
Roads
—1750— Contours
LOCALITY PLAN OF MAPPED AREA
Dunedoo
Uarbry
Ulah
Gulgong
Mudgee
INTERPRETATIVE SECTIONS ALONG A-B & C-D
Legend as for map
Original position of "Fish Bed" Chert before erosion
25·5 m. 75 ft.
450 ft.
152 m.
Section scale

Fig. 1.

Mode of Occurrence of the Fish Bed Chert

The Fish Bed Chert is a hard, fine limonitic cherty-shale containing Jurassic plant and fish fossils perfectly preserved with moderate compression parallel to the bedding. It occurs as loose floating blocks lying in soil on a gently sloping hillside. The occurrence is limited to one main area on the north-eastern side of Farr's Hill and three very small areas on the eastern side, as illustrated in Fig. 1. The main area of occurrence extends for some 900 feet round the hillside, and is about 200 feet wide. The blocks of chert occur most abundantly near the centre of the area on its downhill side. To the north-west, round the hillside, the amount of chert rapidly decreases and then disappears completely to the north-western extremity of the area of occurrence. To the south-east, along the hillside, it also decreases until the area of occurrence terminates at the outcrop of a fault running from south-west to north-east down along a small creek. The fault with a vertical displacement of about 50 feet dislocates all beds outcropping immediately to the north-east of the Fish Bed Chert (see Fig. 1), but it does not extend south-west beyond the top of Farr's Hill.

The three very small areas in which Fish Bed Chert occurs, on the eastern side of Farr's Hill, are situated to the south-east of the fault at a level approximately 50 feet above that of the main area. No Fish Bed Chert, or any other material of similar or related lithology, occurs on the southern, south-western or western sides of Farr's Hill.

The blocks of Fish Bed Chert vary in size from small chips to rectangular slabs measuring as much as 18 inches across the bedding and 24 inches by 24 inches on surfaces parallel to the bedding, and weighing up to 300 and 400 pounds. They all cleave readily along the bedding and exhibit strong jointing at right angles. Nowhere do the blocks of chert occur *in situ*, nor are they arranged in any orderly manner. Small chips are scattered with their bedding at all angles to the horizontal, and the larger slabs are inclined in various directions, but mainly downhill, at angles of up to 20° and 30°.

The possibility of the chert blocks representing the outcrop of a continuous bed extending into Farr's Hill was investigated by sinking a shaft to a depth of 8 feet on the uphill side of the main area of occurrence, near the intersection of section lines A–B and C–D in Fig. 1. The shaft passed down through 18 inches of red-yellow surface soil, 18 inches of light cream-coloured clay with small fragments of fossiliferous chert up to 4 inches in diameter, 24 inches of fine cream-coloured clay with larger scattered blocks of chert up to 9 inches in diameter, and finally through 36 inches of white granular gritty clay without any trace of chert. The fragments and blocks of chert encountered in the shaft were generally smaller, softer, less ferruginous and less abundant than those occurring in the soil at the surface further downhill. The generally inferior nature of the chert occurrence penetrated in the shaft strongly suggests that the surface blocks of Fish Bed Chert do not become more abundant and closely packed underground to form a continuous bed passing into the hillside, as would be expected in the case of the outcrop of a normal flat-lying bed. Similarly, the very limited lateral extent of surface blocks round the hillside at the levels of the areas of occurrence does not indicate a continuous bed of chert extending any significant distance into the hill behind a surface outcrop.

Conclusions

In view of its special features of occurrence, it was concluded that the scattered blocks of Fish Bed Chert, lying on the side of Farr's Hill, represent the displaced erosional remnants, and all that is left of a small marginal section, or arc, of a lens-shaped lake-bed deposit originally situated to the north-east but now almost completely removed by erosion. This is illustrated by means of interpretative sections along lines A–B and C–D in Fig. 1, with reconstruction of the position of the original lens after faulting but before erosion to present surface topography. Based on this interpretation, it follows that excavation of the hillside is unlikely to yield any appreciable additional quantity of Fish Bed Chert.

The relatively small number of larger chert slabs, all of about the same thickness, with very similar lithology and structure in cross-section, strongly suggests that the material all came from one thin bed no more than 24 inches in thickness. This chert lens or lake deposit, with its fossil remains, must have originated under very specialized and unusual conditions of sedimentation, as no other similar occurrence is known in the widespread Purlawaugh sediments with which it is associated. Its palaeo-

geographical position was close to but not actually at the shoreline of Purlawaugh sedimentation which lay along steeply-rising hills of metamorphic basement rocks near Mudgee, 30 miles to the south, and near Gulgong, 20 miles to the south-west (Dulhunty, 1939, 1964; Dulhunty and Packham, 1962). The small fresh-water lake deposit probably accumulated over a relatively short period of time during a temporary cessation or reduction in rate of subsidence in an area of marginal lake environment. Under such circumstances it is difficult to imagine a small isolated lake existing for long. In fact, lack of layering or vertical variation in lithology of the chert suggests rapid deposition over a short period of time. It could represent as little as several seasons' deposit of silt in which the fish and plants were entombed. Alternatively, it may have accumulated over a number of years. Deposition probably proceeded at a rate of at least 0·1 inch per year as many of the almost complete fish skeletons occupying a depth of 0·05 to 0·075 inch in the chert would have disintegrated quickly if not buried. This rate of deposition, with a total thickness of the order of 24 inches, would represent a possible maximum of some 250 years for the life of the lake in which the Talbragar Fish Bed Chert accumulated.

Acknowledgements

In conclusion, the authors wish to acknowledge the assistance of the McMaster brothers of "Argyll", Uarbry, and the Scott brothers of "Cavanders Flat", Uarbry, in providing facilities which enabled field investigations to be carried out.

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Lower Devonian Conodonts from the Lick Hole Limestone, Southern New South Wales

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Abstract—Fifteen species and subspecies of disjunct conodonts are recorded from a measured section of the Lick Hole Limestone. The conodonts, in particular *Polygnathus linguiformis dehiscens* Philip and Jackson, suggest a Lower Devonian (late Siegenian-early Emsian) age for the Lick Hole Limestone.

Introduction

The Lick Hole Limestone is exposed within the valley of the Yarrangobilly River, near Ravine, about 10 miles north-west of Kiandra. This area is part of a larger area mapped by Adamson (1954) and Moye *et al.* (1963), and it is included in the Australian 1 : 250,000 Geological Series, Sheet SI 55–15, Wagga Wagga (Adamson *et al.*, 1966). On these maps a Middle Devonian age is assigned to the Lick Hole Limestone.

The fauna of the limestone has been mentioned by several authors (Andrews, 1901 ; Dun, 1902 ; Harper, 1912 ; Benson, 1922 ; Adamson, *op. cit.* ; Moye *et al.*, *op. cit.*), but Sherrard's (1967) description of two species of Lower Devonian tentaculites—*Tentaculites chapmani* Sherrard and *Nowakia* aff. *acuria* (Richter)—was the first systematic study undertaken. The present paper records the occurrence and age significance of conodonts collected from a measured section of the Lick Hole Limestone, and in an article in preparation, I shall describe the brachiopods, which are the dominant faunal element of the formation.

Stratigraphy

In the Lob's Hole-Ravine area two distinct groups of sediments may be recognized : the Ravine Beds of Upper Silurian age, and the unconformably overlying Byron Range Group, partly at least of Lower Devonian age. The latter group consists of three conformable formations, in ascending order, Milk Shanty Formation (550 ft.), Lick Hole Limestone (1,600 ft.), and Round Top Formation (50 ft.). This succession, based partly on the work of Adamson (*op. cit.*), Moye *et al.* (*op. cit.*), and partly on original observation, is shown in Figure 1.

Ravine Beds

This group (Moye *et al.*, *op. cit.*) consists of greywacke, conglomerate, and siltstone. These sediments appear to be unfossiliferous, but limestone has been located in a drill hole at Ravine (Jacquet, 1918). Moye *et al.* (*op. cit.*) tentatively correlate it with the Silurian, Yarrangobilly Limestone, which crops out some ten miles north of Ravine.

Byron Range Group

Unfossiliferous, hematite-stained siltstone, current-bedded sandstone, and conglomerate typify the lowest unit of the Byron Range Group (Moye *et al.*, *op. cit.*), known as the Milk Shanty Formation (Adamson, *op. cit.*). They are followed by richly fossiliferous, interbedded, bluish-grey mudstone, drab olive-grey, calcareous mudstone, and dark, fine-grained biogenic nodules and discontinuous nodular layers. The calcareous mudstone locally display current bedding, and sandy oolite bands occur in the upper part of the sequence. The uppermost 300 feet of sediment consists of unfossiliferous mudstone. This sequence has been referred to as the Lick Hole Limestone (Moye *et al.*, *op. cit.*). This in turn is succeeded by the Round Top Formation (Adamson, *op. cit.*), which includes interbedded red sandstone, maroon siltstone, and minor greenish-grey siltstone. Moye *et al.* (*op. cit.*, p. 20) record the presence of molluscs

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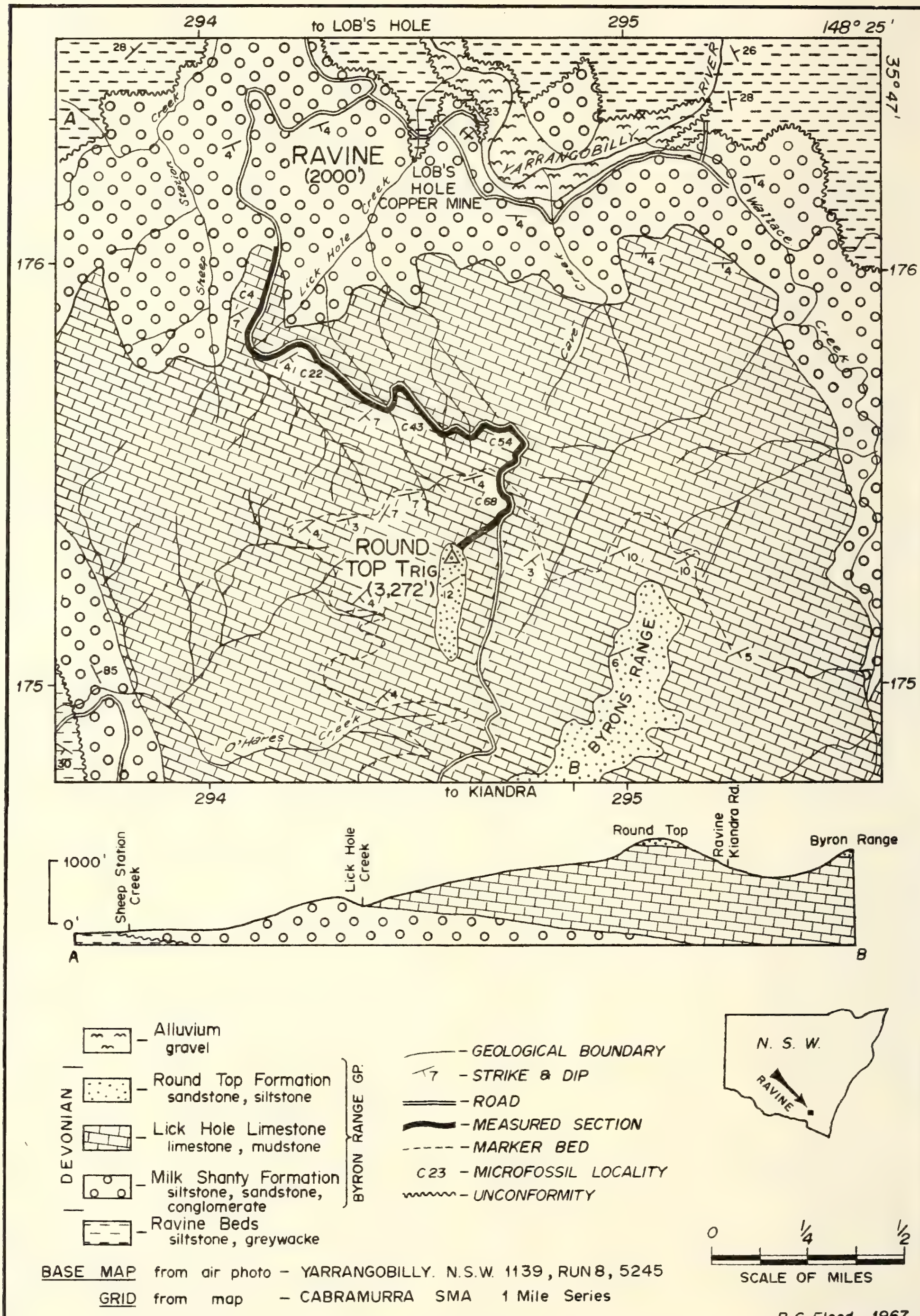


Fig. 1

Geological map, Ravine area.

in the " lowest quartzite beds ". An examination of these beds failed to reveal molluscs, but instead numerous inarticulate brachiopods (*Lingula* sp.) were collected.

The Conodont Fauna

Some 1,300 identifiable conodonts were recovered, using standard acetic acid techniques, from the insoluble residue of 200 kilogrammes of limestone, representing 42 samples collected throughout the measured section. Systematic descriptions are omitted because all the recovered species have been described previously. Some have been recorded from the Buchan Group (Philip, 1966), and some from the Murrumbidgee Group (Pedder, Jackson, and Philip, 1969).

The fauna includes the following forms :

- *Hibbardella perbona* (Philip, 1966),
- *Hindeodella priscilla* Stauffer, 1938,
- *Ligonodina salopia* Rhodes, 1953,
- *Lonchodina* n.sp. Philip, 1966,
- *Lonchodina* sp. indet.
- *Neoprioniodus bicurvatus* (Branson and Mehl, 1933),
- *Ozarkodina typica denckmanni* Ziegler, 1956,
- *Ozarkodina typica australis* Philip and Jackson, *in* Pedder *et al*., 1969,
- *Plectospathodus alternatus* Walliser, 1964,
- *Polygnathus linguiformis dehiscens* Philip and Jackson, 1967,
- *Spathognathodus linearis* (Philip, 1966),
- *Spathognathodus steinhornensis optimus* Moskalenko, 1966,
- *Trichonodella inconstans* Walliser, 1957,
- *Trichonodella symmetrica pinnula* Philip, 1966.

Figure 2 shows that several long-ranging Lower Devonian conodonts persist through the entire sequence. The presence, however, of the index conodont of the *Polygnathus linguiformis dehiscens* conodont assemblage (Philip and Jackson, 1970) suggests, in terms of the existing knowledge of the sequence of Lower Devonian conodonts in eastern Australia, a late Siegenian-early Emsian age for the Lick Hole Limestone.

The Measured Section

The section is located at Ravine, south of the Yarrangobilly River, and follows, for approximately one and a half miles, the Ravine-Kiandra road. The section begins at G.R. 29421760 and ends at G.R. 29461753, and was measured with tape, abne and compass by A. E. H. Pedder and P. G. Flood in January, 1967.

Unit No.		Thickness in Feet: Unit	Thickness in Feet: Total from Base
	Round Top Formation		
	Interbedded olive-grey siltstone and maroon sandstone ; contact with underlying formation is distinct but conformable	47	
	Lick Hole Limestone		
5	Mudstone, olive-grey, poorly bedded, poorly exposed, no fossils observed	300	1,600
4	Olive-grey mudstone and interbedded, dark, microcrystalline calcareous nodules ; rare occurrence of brachiopods	120	1,300
3	Massive, bluish-grey calcareous mudstone, and numerous biogenic nodules and nodular layers ; crowded with brachiopods, rarer bryozoan, and solitary rugosan ; upper part of the unit is ledge forming and provides an excellent marker bed	360	1,180
2	Olive-green mudstone, and thin biogenic nodular-limestone interbeds ; brachiopods and pelecypods present	522	820
1	Bluish-grey mudstone, and dark grey, calcareous siltstone ; few brachiopods present	298	298
	Milk Shanty Formation		
	Well-bedded, maroon siltstone, hematite-stained sandstone and conglomerate ; contact with overlying formation is distinct but conformable		

Acknowledgements

I am indebted to A. E. H. Pedder, J. H. Jackson and G. M. Philip for supplying a copy of their manuscript on the Lower Devonian Biostratigraphy in the Wee Jasper region of New South Wales in advance of publication. The present paper is published with the permission of the Director of the Bureau of Mineral Resources, Geology and Geophysics, Canberra, A.C.T.

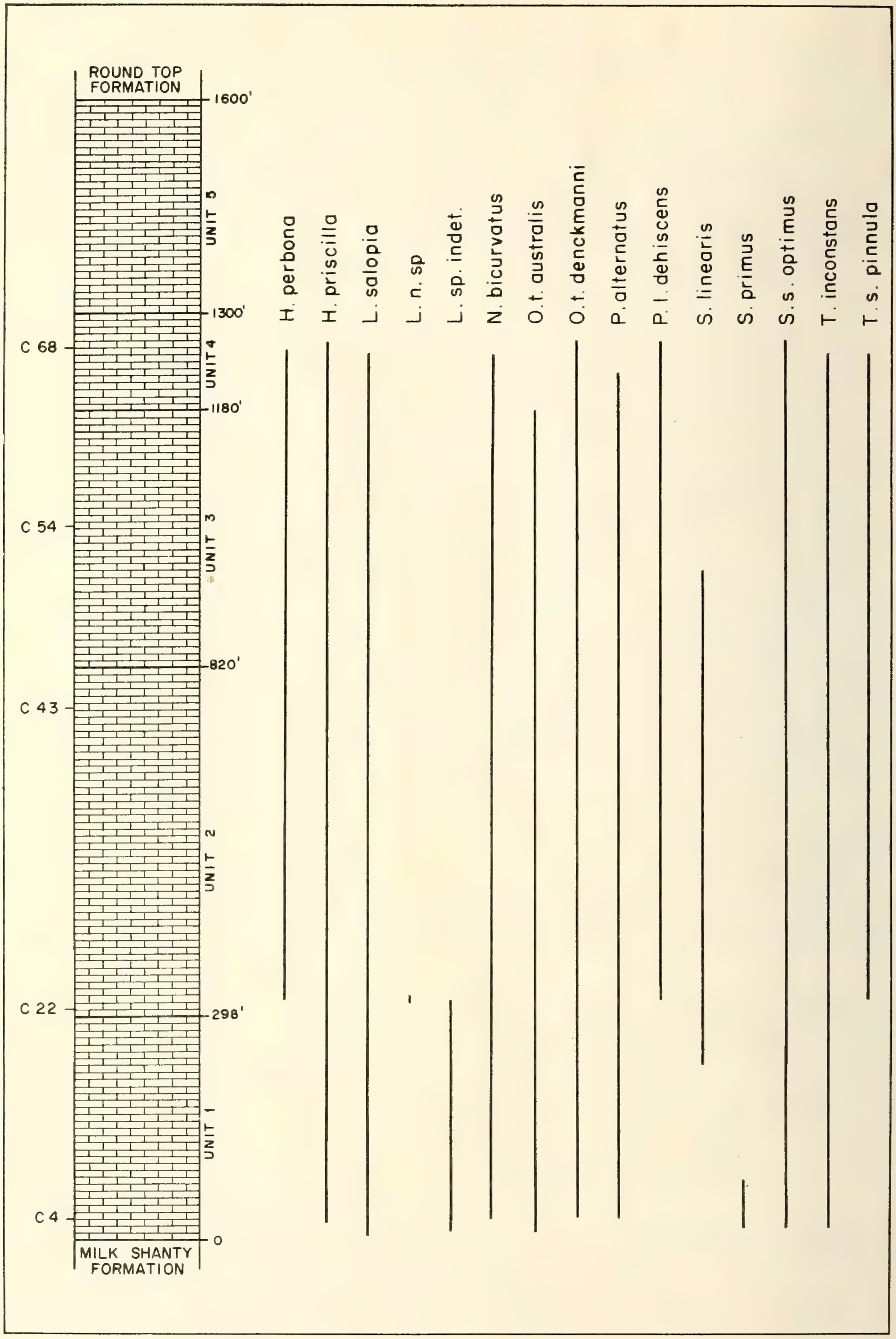
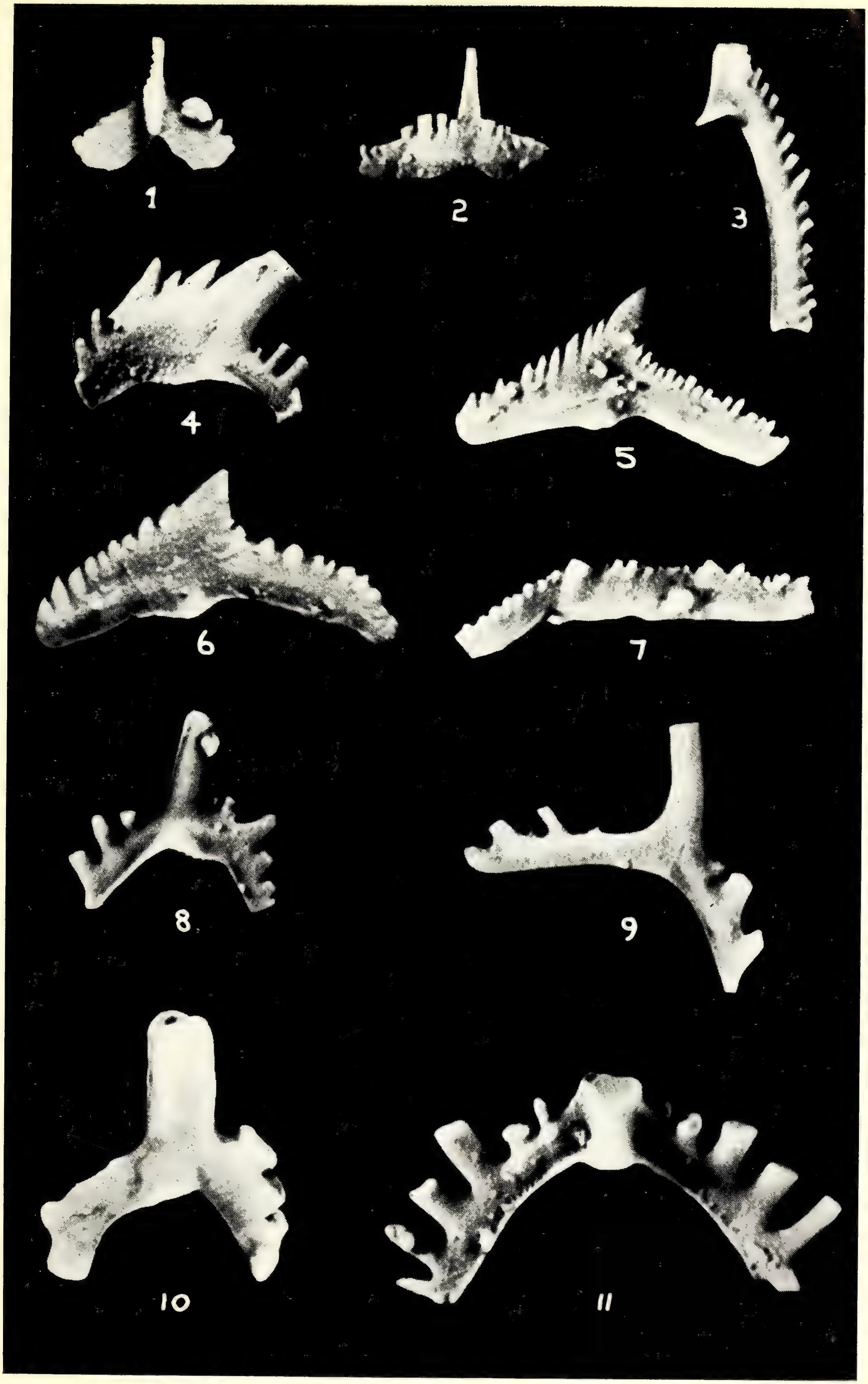


Fig. 2

Minimum teilzones of the conodont forms, mentioned in the text, within the measured section of the Lick Hole Limestone.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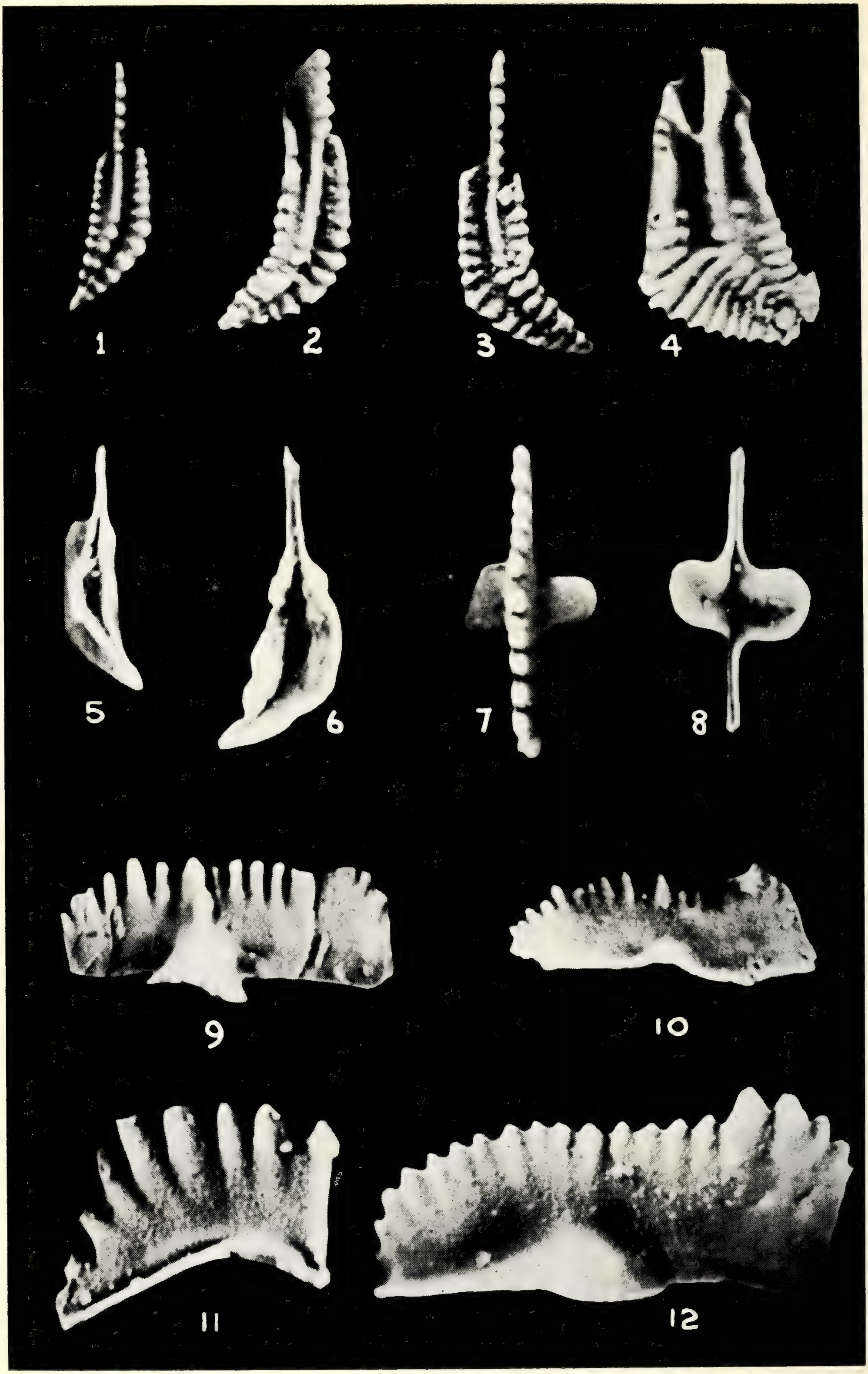
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Addendum

While this article was at press, G. Klapper (*J. Palaeont.* (1969), 43 (1), 1–27) published results of conodont studies from Royal Creek, Yukon, Canada. Several of the Royal Creek forms are identical to specimens from the Lick Hole Limestone. Of special importance is the occurrence of *Polygnathus lenzi* Klapper (=*Polygnathus linguiformis dehiscens* Philip and Jackson), to which he assigns an early Emsian age.

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Explanation of Plates

All figures ×40 and specimens registered in the University of New England Palaeontological Collection.

PLATE I

FIG. 1.—*Hibbardella perbona* (Philip). Posterior view of 10304/I, locality C22.
FIG. 2.—*Trichonodella symmetrica pinnula* Philip. Anterior view of 10304/II, locality C22.
FIG. 3.—*Neoprioniodus bicurvatus* (Branson and Mehl). Inner view of 10304/3, locality C22.
FIG. 4.—*Ozarkodina typica australis* Philip and Jackson. Lateral view of 10305/I, locality C24.
FIGS. 5, 6.—*Ozarkodina typica denckmanni* Ziegler. Lateral views of 10307/1–2, locality C54.
FIG. 7.—*Plectospathodus alternatus* Walliser. Inner view of 10304/4, locality C22.
FIG. 8.—*Lonchodina* n.sp. Philip. Lateral view of 10304/2, locality C22.
FIG. 9.—*Ligonodina salopia* Rhodes. Inner view of 10303/2, locality C4.
FIG. 10.—*Lonchodina* sp. indet. Posterior view of 10306/2, locality C43.
FIG. 11.—*Trichonodella inconstans* Walliser. Posterior view of 10304/8, locality C22.

PLATE II

FIGS. 1–6—*Polygnathus linguiformis dehiscens* Philip and Jackson.
1–4. Oral views of 10307/5,11,6, locality C54, 10306/4, locality C43.
5, 6. Aboral views of 10307/10,9, locality C54.
FIGS. 7–10.—*Spathognathodus steinhornensis optimus* Moskalenko.
7. Oral view of 10306/6, locality C43.
8. Aboral view of 10307/14, locality C54.
9, 10. Lateral views of 10306/7, locality C43, 10303/6, locality C4.
FIG. 11.—*Spathognathodus primus* (Branson and Mehl). Lateral view of 10302/1, locality C2.
FIG. 12.—*Spathognathodus linearis* (Philip). Lateral view of 10304/7, locality C22.

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Granitic Development and Emplacement in the Tumbarumba-Geehi District, N.S.W.

(1) The Foliated Granites

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Abstract—In the Tumbarumba-Geehi district some of the granitic bodies that are in part foliated display a close association in mineralogy, chemistry and field relationships with the surrounding regionally metamorphosed psammopelitic sequence. These foliated rocks—the Cooma-type granites—are characterized by the presence of clusters of biotite, occasional cordierite and patchy zoning in the plagioclases. Chemically the rocks display low Ca contents and a high K : Na ratio, features that are evident in the associated metamorphics. There is a distinct similarity in the chemistry of biotites from the granites, their inclusions, and the high-grade metamorphics.

The following sequence of events is envisaged for the formation and emplacement of the Cooma-type granites : (*a*) high-grade metamorphism of a psammopelitic sequence, segregation of quartzo-feldspathic and biotite-rich sections, and some increase in Ca contents; (*b*) introduction of sodium, breakdown of micas and the formation of a partial melt, with development of alkali feldspars. Such reactions involve an increase in volume and thus a decrease in specific gravity of the granites with consequent migration and emplacement to higher levels in the crust.

Introduction

The granitic* rocks of the Tumbarumba-Geehi district, N.S.W. may be classified into several groups on the basis of their textural and mineralogical features and field association with regional metamorphic zones. The aim of this paper is to describe and consider the development of one of the groups—the Cooma-type granites (Vallance, 1967)—with particular reference to its relationship to the surrounding regional metamorphics. The other granitic rocks present (Khancoban, Mannus Creek and Dargals granites) post-date the regional metamorphism and will be discussed in a later paper. The distribution of rocks in the Tumbarumba-Geehi district has been noted elsewhere (Guy, 1969).

The Cooma-type granites of south-east Australia include the Cooma gneiss (Joplin, 1942), Albury gneiss (Joplin, 1947), Wantabadgery granite (Vallance, 1953), Mt. Wagra gneiss (Tattam, 1929) as well as the Corryong and Geehi granites of the Tumbarumba-Geehi district. The Corryong granite is part of a large batholith that extends from south-west of Corryong, Victoria to near Adelong, N.S.W. Portions of the mass were described by Edwards and Easton (1937) and later by Hall and Lloyd (1950), the latter authors applying the term Maragle Batholith. Vallance (1953) applied the name Green Hills granite to that section of the mass to the north of Tumbarumba. The Geehi granite forms part of a south-easterly extension of the Corryong granite but no investigation concerning the continuity of these bodies has been undertaken in connection with this study.

The Corryong and Geehi granites are medium grained, remarkably uniform rocks with a high biotite content and free from hornblende; massive in part but generally foliated. This foliation is delineated by a parallelism of bladed micas and elongated xenoliths. The foliation is steeply dipping and has a general trend north-south, and locally parallel to the contacts with the surrounding psammopelitic sequence of Ordovician rocks.

Mineralogy and Petrology

The normal granitic rocks vary from granits (s.s.) to granodiorite, with the bulk of the rocke being grey adamelites (Table 1). The grain size is even (1–2 mm.) though coarser types with alkali feldspars to 8–10 mm. occur and also some tendency for minerals to be present in clusters, especially biotite. Cell structures with-

* Unless otherwise stated, the term " granitic ", as used in this paper, applies to deep-seated bodies that may be acid-intermediate in composition.

in the quartz grains are evident and sometimes assume a typical polygonal arrangement (Plate 1a). The larger alkali feldspars enclose quartz and plagioclase, suggesting their development later than other phases. Alkali feldspars are optically monoclinic although some cross-hatch twinning occasionally occurs. The triclinicity, $\triangle$, (Goldsmith and Laves, 1954) is in the range 0·25–0·40, and $2V\alpha$=80–90°. The K : Na ratio of the alkali feldspars may be estimated utilizing modal and chemical data (including plagioclase and biotite compositions), for specimen 21800 and for the biotite-granite from Vallance (1953, 1960). If assumptions are made as to the compositions of the micas and the accessory minerals, the K : Na ratio may also be estimated for specimens 21805, 21777. All such Or percentages fall in the range 62–68%. The plagioclases are more calcic than those noted by Vallance (1953) in the area north of Tumbarumba, where most contain 30–35% anorthite molecule. The average composition for plagioclases from the present area is An_{34-40}*, variation being from An_{55} (at core) to An_{20} (at margin). The calcic character of these plagioclases is of interest considering the relative low Ca contents of the rocks (Table 1). Most of the plagioclase grains are twinned, with up to four laws being present. A large number of plagioclases contain small areas, somewhat irregular in shape and distribution, that are at a slightly different optical orientation from the main portion of the crystal (Plate 1b). This "patchiness" displayed by the plagioclase is more evident in varieties where zoning rather than twinning is prominent. The outlines of these small areas is often partly controlled by twinning. Such small patches differ in optical orientation by only a few degrees from the host and do not obey any recognizable twin law. Most plagioclases have $2V\gamma$ from 70–85°, although sodic varieties have $2V\alpha$=85–88°. Biotite is present in clusters with blades being intergrown and occasionally twinned. Generally it is pleochroic red-brown, although some dark olive-brown biotites have been recorded. γ-ranges from 1·643 to 1·651. One red-brown biotite has been analysed from the present area (Guy, 1964) and its composition is summarized below (No. 1)—specimen 21800†, together with a biotite (No. 2) from the area to the north of Tumbarumba (Vallance, 1960).

TABLE 1

Chemical Analyses, Barth Mesonorms and Modes of Corryong and Geehi Granites

	1	2	3	4
SiO_2 ..	70·25	69·40	69·70	69·05
TiO_2 ..	0·41	0·49	1·15	0·29
Al_2O_3 ..	13·78	13·58	13·30	15·78
Fe_2O_3 ..	0·41	0·75	0·27	0·22
FeO ..	3·04	3·87	3·60	3·62
MnO ..	0·07	0·11	0·05	0·05
MgO ..	1·49	2·04	1·66	2·15
CaO ..	1·80	0·92	1·92	2·50
Na_2O ..	2·41	2·01	2·51	2·49
K_2O ..	4·86	5·14	4·25	3·85
P_2O_5 ..	0·16	0·04	0·15	n.d.
H_2O^+ ..	1·13	1·64	0·94	0·28
H_2O^- ..	0·07	0·04	0·09	0·13
Total	99·88	100·03	99·59	100·41
Q ..	32·96	35·10	34·49	32·54
Or ..	22·12	21·70	17·30	13·33
Ab ..	22·30	18·70	23·30	22·60
An ..	6·60	2·75	4·70	11·55
C ..	2·54	4·22	3·27	3·69
Bi ..	11·89	15·60	13·84	15·47
Ap ..	0·35	0·08	0·32	—
Ti ..	0·89	1·05	2·49	0·60
Mt ..	0·43	0·81	0·30	0·24
Quartz ..	30·0	39·6	39·7	31·4
Plagioclase	31·9	14·5	26·9	26·2
K-feldspar	17·6	23·8	13·2	24·0
Biotite ..	10·2	13·4	9·6	9·3
Muscovite	5·7	4·5	3·7	7·2
Cordierite	1·4	1·2	0·2	1·0
Inclusions[a]	3·2	2·1	5·4	0·5
Accessories[b]	0·1	0·7	1·3	0·5

[a] Included pelitic fragments (mainly muscovite, chlorite and quartz).
[b] Apatite, sillimanite, tourmaline, rutile.

1. Spec. No. 21842. Biotite adamellite. G.R.267.0–160.2* (Corryong granite).
2. Spec. No. 21847. Biotite adamellite. G.R.284.6–139.6 (Geehi granite).
3. Spec. No. 21800. Granodiorite. G.R.276.8–165.9 (Corryong granite).
4. Spec. No. 21777. Biotite adamellite. G.R.274.9–174.1 (Corryong granite).

Analyst: B. Guy.

* Snowy Mountains Authority grid reference (see Guy, 1969).

1. $(K_{0\cdot75}\ Na_{0\cdot05}\ Ca_{0\cdot04})\ (Al_{0\cdot36}\ Ti_{0\cdot13}\ Fe^{3+}_{0\cdot13}\ Fe^{2+}_{1\cdot19}\ Mg_{0\cdot98}\ Mn_{0\cdot01})\ (Si_{2\cdot74}\ Al_{1\cdot26})\ O_{10}\ (OH)_2$

2. $(K_{0\cdot84}\ Na_{0\cdot08}\ Ca_{0\cdot03})\ (Al_{0\cdot45}\ Ti_{0\cdot18}\ Fe^{3+}_{0\cdot22}\ Fe^{2+}_{1\cdot06}\ Mg_{0\cdot83}\ Mn_{0\cdot01})\ (Si_{2\cdot71}\ Al_{1\cdot29})\ O_{10}\ (OH)_2$.

* Compositions of the plagioclases were determined from the extinction angle X'^(010) ⊥ [100] measured on a universal stage and referred to the low-temperature determinative curves of Bordet (1963).

† Further details of the analysed biotites will be published in a later communication.

Muscovite is significant as large blades in the Cooma-type granites but cross-cutting other constituents, and is associated with biotite which it may be replacing. The percentage of muscovite increases with increasing alkali feldspar content. About 2–3% of the granitic rocks is composed of cordierite or inclusions of pelitic material. The cordierite appears as anhedral grains (1–2 mm.) in part replaced by muscovite. It is homogeneous with $2V\alpha=80°$. Patches of sheet silicates, assuming ovoid shapes and 1–3 mm. in size, are ubiquitous in the granitic rocks. They are composed of chlorite, muscovite with some quartz, biotite and sillimanite. Texturally these micaceous aggregates appear as inclusions in the host granite. They may in part represent pseudomorphs after cordierite. Accessory minerals in the granitic rocks are opaque oxides, tourmaline, apatite, sillimanite, zircon, rutile, monazite, calcite and epidote. Marginal phases of the granites have high tourmaline and muscovite contents, with biotite being replaced by these two minerals.

Throughout these granites shear zones are numerous, varying from 5 cm. to a metre in width, though Vallance (1953) and Beavis (1961) describe crush bands several hundred metres wide in similar granitic rocks. Shearing effects produce some reduction in grain size with assemblages such as "quartz-feldspar-chlorite-muscovite" being produced.

Aplites, pegmatites and graphic granites form significant occurrences in the Cooma-type granites. Aplites occur as small veins occupying joints. Quartz, optically monoclinic alkali feldspar and oligoclase are the dominant phases, being in approximately equal quantities. Dark-green biotite, muscovite, tourmaline, apatite and opaque oxides are accessories. Tourmaline-rich bands characterize many of the aplitic veins. Pegmatites are mineralogically similar to the aplites, but oligoclase is subordinate. Tourmaline in the pegmatites has a basal parting (up to 0·5 mm. wide) filled with quartz and iron oxides.

Associated with the aplitic and pegmatitic phases are dark, fine grained dykes consisting essentially of chlorite and tourmaline with some quartz and opaques. These rocks are prevalent in the area south of Tumbarumba and are associated with shear bands in the granite and quartz-sulphide veins. Although the original composition has presumably been extensively modified, they may represent basic dykes that have been sheared and altered by hydrothermal activity.

Large inclusions (>5 cm.) are prominent throughout the Corryong and Geehi granites, being of psammitic to pelitic character and mineralogically and texturally similar to the high-grade regional metamorphics of the district (Guy, 1969). Some quartz nodules (5–10 cm. in size) are also common throughout the Cooma-type granites. Most inclusions differ from the country rocks in that plagioclase is significant in the former rock type as porphyroblasts of An_{35} composition. The plagioclase is euhedrally zoned with cores of An_{50}, and $2V\gamma=80–90°$; some "patchiness", as described for plagioclases of the granitic rocks, is evident. Biotite is present throughout all the inclusions, and is frequently concentrated around the margins of the larger sandier types. Structural formulae for some biotites are noted below. Nos. 1 and 2 are red-brown types ($\gamma=1{\cdot}645$) common to most inclusions, while Nos. 3 and 4 are yellow-brown varieties ($\gamma=1{\cdot}625$) noted in some of the sandier rocks. No. 1 is from Vallance (1960) and the remainder from Guy (1964). Modal analyses of the host inclusions are noted in Table 2.

1. $(K_{0\cdot82}\ Na_{0\cdot12}\ Ca_{0\cdot03})\ (Al_{0\cdot37}\ Ti_{0\cdot17}\ Fe^{3+}_{0\cdot20}\ Fe^{2+}_{1\cdot11}\ Mn_{0\cdot04}\ Mg_{1\cdot04})\ (Si_{2\cdot65}\ Al_{1\cdot35})\ O_{10}\ (OH)_2$
2. (Spec. 21798) $(K_{0\cdot90}\ Na_{0\cdot12}\ Ca_{0\cdot02})\ (Al_{0\cdot44}\ Ti_{0\cdot12}\ Fe^{3+}_{0\cdot11}\ Fe^{2+}_{1\cdot10}\ Mn_{0\cdot01}\ Mg_{0\cdot97})\ (Si_{2\cdot67}\ Al_{1\cdot33})\ O_{10}\ (OH)_2$
3. (Spec. 21807) $(K_{0\cdot81}\ Na_{0\cdot16}\ Ca_{0\cdot00})\ (Al_{0\cdot30}\ Ti_{0\cdot05}\ Fe^{3+}_{0\cdot90}\ Fe^{2+}_{0\cdot62}\ Mn_{0\cdot00}\ Mg_{1\cdot77})\ (Si_{2\cdot89}\ Al_{1\cdot11})\ O_{10}\ (OH)_2$
4. (Spec. 21787) $(K_{0\cdot79}\ Na_{0\cdot08}\ Ca_{0\cdot03})\ (Al_{0\cdot32}\ Ti_{0\cdot05}\ Fe^{3+}_{0\cdot09}\ Fe^{2+}_{0\cdot82}\ Mn_{0\cdot01}\ Mg_{1\cdot59})\ (Si_{2\cdot80}\ Al_{1\cdot20})\ O_{10}\ (OH)_2$

The Mg-rich micas (Nos. 3 and 4) have only been observed or suspected in these inclusions, whereas they appear to be lacking in the granite and regional metamorphics. The lower grade metamorphics may prove to contain some exceptions (Guy, 1969, Table 1). The silica content is appreciably higher for these Mg-rich varieties.

Cordierite is abundant in the pelitic inclusions as ragged crystals with a distortion index, $\triangle$, (Miyashiro, 1957) of $0{\cdot}19\pm0{\cdot}03$ and $\beta=1{\cdot}553\pm0{\cdot}003$, indicating (ca.) 25% Fe substitution for Mg. Sillimanite is present in the fibrolite form, although numerous needle-like crystals are associated with the matted fibrolite. Muscovites in the inclusions vary from large blades (2–3 mm. long), cross-cutting other minerals,

to sericitic varieties which replace nearly all the phases except quartz. Chlorite, in part after cordierite, may be associated with the fine matted micas.

TABLE 2

Chemical Analyses, Barth Mesonorms and Modes for Inclusions in Cooma Type Granites

	1	2	3	4	5	6
SiO_2 ..	66·27	57·70	54·86	54·22	45·73	44·87
TiO_2 ..	0·88	1·80	1·18	1·78	0·13	2·50
Al_2O_3 ..	13·85	14·17	18·32	21·01	27·83	28·42
Fe_2O_3 ..	0·27	0·28	2·01	1·79	1·05	0·26
FeO ..	3·55	7·36	8·01	5·61	6·80	7·97
MnO ..	0·06	0·13	0·14	0·14	0·06	0·26
MgO ..	5·50	7·23	4·16	2·43	4·95	4·45
CaO ..	2·54	3·35	1·95	0·49	0·20	1·49
Na_2O ..	2·57	0·73	2·46	1·75	0·27	2·02
K_2O ..	3·01	4·51	5·22	7·41	8·17	3·71
P_2O_5 ..	0·01	0·12	—	0·31	n.d.	0·12
H_2O^+ ..	0·90	1·90	1·30	2·46	4·00	3·40
H_2O^- ..	0·18	0·23	0·22	0·36	0·40	0·23
F_2 ..	—	—	—	—	0·06	—
Less O for F_2 ..	—	—	—	—	0·03	—
Total	99·59	99·51	99·83	99·76	99·62	99·70
Q ..	33·05	29·61	16·46	15·04	12·14	16·80
Or ..	0·62	0·55	12·18	33·10	29·82	1·25
Ab ..	23·45	6·80	22·60	16·35	2·50	18·75
An ..	9·60	9·90	5·70	—	0·60	—
C ..	3·22	5·22	7·37	11·48	20·83	23·81
Bi ..	27·89	43·44	30·99	19·92	32·69	34·32
Ap ..	0·03	0·27	—	0·67	—	0·27
Ti ..	1·86	3·90	2·52	0·33	0·27	4·08
Mt ..	0·28	0·30	2·16	1·95	1·14	0·28
Rt ..	—	—	—	1·18	—	0·44
Quartz ..	34·9	28·5	22·2	*	*	0·2
Alkali feldspar	1·3	—	1·6	*	*	0·3
Plagioclase	32·8	22·3	24·4	*	*	15·7
Biotite ..	31·0	47·9	42·3	*	*	20·6
Muscovite	—	1·1	8·4	*	*	20·7
Cordierite	—	—	—	*	*	37·5
Sillimanite	—	—	(Present)	*	*	3·1
Accessories	—	0·1	1·0	*	*	2·0

1. Spec. No. 21807. Biotite-quartz-plagioclase rock. G.R. 278.5–175.4.
2. Spec. No. 21787. Biotite - rich psammopelite. G.R. 274.1–155.8.
3. Biotite-rich patch in granodiorite. Tenandra Trig. Vallance (1953).
4. Micaceous xenolith in granite, Mt. Wagra. Tattam (1929).
5. Pinitized cordierite inclusion, Kerungah Gap. Tattam (1929).
6. Spec. No. 21798. Cordierite-biotite-sillimanite rock. G.R. 277.2–165.2.

Analysts: 1, 2, 6—B. Guy. 3—T. G. Vallance. 4, 5—C. M. Tattam.

* Data not available.

Chemical Data

(i) Granitic Rocks. Four new analyses of granitic rocks from the Cooma-type granites are presented in Table 1. The granites are characterized by high Al_2O_3 contents, low CaO and a $K_2O : Na_2O$ ratio higher than unity. Chemical data have been summarized in Fig. 1.

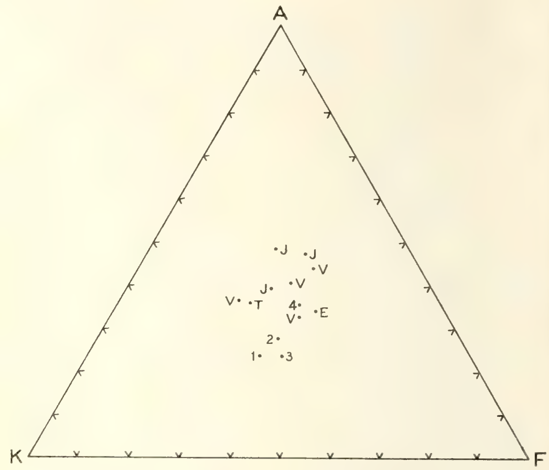

FIG. 1—AKF diagram for the Cooma-type granites. Analytical data from Table 1, this paper (Nos. 1, 2, 3, 4); Tattam, 1929 (T); Edwards and Easton, 1937 (E); Joplin, 1942 and 1947 (J); Vallance, 1953 (V).

Many of the rocks contain less than 80% normative AB+Or+Q and thus would not be classified by Tuttle and Bowen (1958) as granites* (s.s.).

(ii) Inclusions. Three new analyses are listed for inclusions from the Cooma-type granites in Table 2, together with analyses from Vallance (1953) and Tattam (1929). An examination of modes and the analytical data for the inclusions reveals a close correspondence indicating that the phases have compositions close to the ideal normative minerals calculated. Utilizing the biotite analysis for specimen 21798, together with the modal data, the Mg : Mg+Fe+Mn value for the cordierite of this specimen may be estimated at (ca.) 0·6. The associated biotite has a value of 0·44.

The Mg : Mg+Fe+Mn ratio averages 0·40 both for the Cooma-type granites in south-east Australia and the pelitic rocks in the associated Ordovician sequence, while the associated psammopelites and the psammites average 0·33. Inclusions of the latter rock type (Table 2) have an Mg : Mg+Fe+Mn ratio of 0·67.

* Tuttle and Bowen utilized C.I.P.W. norms, whereas Barth mesonorms have been used in Table 1.

TABLE 3

Anions Associated with Cations in Metasediments, Inclusions and Granites*

(?) Unmetamorphosed or Low-grade Zone	Biotite Zone	Knotted Schist Zone	High-grade Zone	Inclusions	Granites
(*a*) Psammites and Psammopelites					
186·55	182·17	188·06	174·46	169·53	170·04
—	185·04	—	178·01	167·80	170·94
—	—	—	181·39	—	170·95
Average : 186·55	183·61	188·06	177·95	168·67	172·57
(*b*) Pelites					173·45
162·13	175·18	172·39	167·13	163·96	173·76
173·58	175·74	172·45	167·22	167·07	173·85
173·67	177·13	172·77	167·67	167·86	174·75
175·52	—	173·44	169·41	167·89	175·36
178·65	—	174·80	170·19	—	175·41
179·22	—	175·41	171·64	—	175·54
185·14	—	181·81	—	172·08	175·78
185·67	—	183·10	—	—	179·89
Average : 177·95	176·02	174·65	169·29	166·70	173·92

* Cations summed to 100.00.
See Figs. 1 and 2 for references to analytical data on granites, and Guy (1969) for data on metasediments.

Anions associated with 100 cations in the Cooma-type granites, their inclusions and the Ordovician metasediments are listed in Table 3. The metasediments show a general trend of decrease in the number of associated anions from low grade through to the inclusions with an increase of (ca.) 4% from the inclusions to the granites.

Figures 1 and 2 summarize some of the chemical features of the metasediments, the inclusions and the Cooma-type granites.

Origin of the Granitic Rocks

The spatial distribution of the Cooma-type granites relative to the regional metamorphic zonal sequence and the high amount of included material in the granite suggest a close association between granite and surrounding country rock material. Mineralogically this is evident in that cordierite may be present in the granitic rocks and there is a similarity in the optical and chemical properties of the biotites in the metasediments and granite. The metasediments are characterized by a restricted chemical nature (Guy, 1969) being rich in alumina and potash, low in lime and soda, while the Cooma-type granites display a similar nature in that alumina and potash contents are high, with lime being low but slightly more significant than in the metasediments. Soda, however, is present in appreciable proportions in the granites. Vallance (1953) estimated the country rocks in the Wantabadgery area have an average composition of a psammopelite, with the ratio pelite :

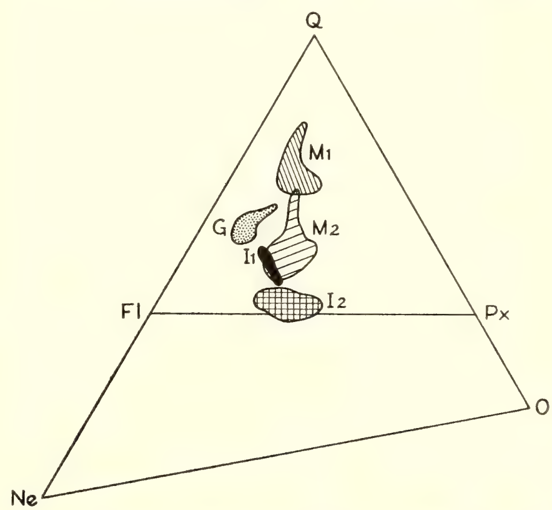

FIG. 2—Q-Fl-Px diagram showing the general distribution of Cooma-type granites (G), their inclusions (I_1, psammopelites ; I_2, pelites) and Ordovician metasediments (M_1, psammopelites ; M_2, pelites). See Guy (1969) for references to the analytical data of the metasediments.

psammopelite : psammites being 20 : 60 : 20. This approximation appears to be a satisfactory estimate of the relative proportions of such rocks in the Tumbarumba-Geehi district. Vallance observed that such an average " psammopelite " was chemically similar to the granite except for a deficiency in the Na and Ca in the former rock, and suggested that granites were derived largely from materials of the sedimentary pile.

Joplin (1962) has postulated the idea of an oligoclase magma being added to the " psammopelitic " sequence to produce the Cooma-type granites. It is doubtful if such a magma is really necessary to form such granites ; indeed Kolbe and Taylor (1966) have argued against this mainly on the basis of K : Rb ratios in these rocks. These latter authors, together with Pidgeon and Compston (1965), have suggested derivation of the Cooma-type granites entirely from the surrounding metasedimentary sequence. Joplin (1962) does not adhere to the idea of melting *in situ* alone because of the steep thermal gradients as indicated by the metamorphic zones surrounding the granite masses. Field relationships between granitic and metamorphic rocks in the Wantabadgery area led Vallance (1953) to suggest that the granites there probably developed at some lower level and were later emplaced at a higher level in the crust. Similar relations exist in the Tumbarumba-Geehi district.

Previous investigations of the Cooma-type granites have demonstrated that such rocks are derived primarily from metasediments similar to those exposed in Ordovician areas of south-east Australia. As yet there is little detailed information regarding the mineralogical processes involved in the transformation to such granites, or on the physical state of the metasediments during transformation. Before considering these aspects several important features of the Cooma-type granites should be emphasized. The granites are broadly homogeneous in that textural and mineralogical features are reasonably constant throughout the various bodies. However, on the scale of an outcrop (several square metres), such rocks are characteristically heterogeneous with numerous inclusions (>2 cms.) occupying up to 10–15% of an exposure. Smaller inclusions (<2 cms.), not always readily discernible macroscopically, may occupy 5% (see Table 1) of such granites. Clustering of mineral phases is particularly evident with the micas but also present in quartzo-feldspathic sections. Thus a granite analysis as quoted in the text and figures represents but an average of these features, while the bulk chemistry of, say, the Corryong granite cannot possibly be represented by " granite " analyses alone.

The predominance of included country rock material in the granites, the similarity in mineralogical features to both the metasediments and the granitic rocks, and the textural features outlined above suggest that the inclusions are at an intermediate stage in the transformation to granitic material rather than a " by-product " of granitic development. Most of the inclusions contain mainly quartz and biotite with minor plagioclase feldspar as well as cordierite, sillimanite, etc. The inclusions are mica-rich and from the analytical data (see Fig. 2) contain markedly lower quantities of silica than the metasediments. Thus transformation from metasediment to inclusion may involve a segregation into a quartz or quartzo-feldspathic section and a mica-rich section. The mica-rich sections are obvious on a microscopic to a macroscopic scale. The lighter coloured portions are not immediately apparent in the vicinity of biotite-rich areas. The quartzo-feldspathic components may have been able to diffuse into their surroundings or migrate some distance—perhaps to contribute to the aplitic, pegmatitic and graphic granite phases that are common throughout the Cooma-type granites. The predominance of quartz over feldspars in the metasediments could have resulted in the segregation of quartz-rich areas. Quartz nodules throughout the granite may be representatives of this segregation. The process of segregation is conceivably a continuation of the regional metamorphic processes with diffusion being a principal agent by which rearrangement of material takes place. Most of the inclusions contain small amounts of plagioclase. This plagioclase is somewhat similar to that observed in the granitic rocks and is reasonably calcic (cores of An_{50} have been recorded). The feldspars are discussed in more detail below (see p. 17). From an examination of Table 3, it is evident that the number of anions associated with 100 cations decreases with increasing grade of metamorphism. This effectively means that with increase in grade (until the stage of inclusions) there is a decrease in the overall volume of the rocks ($\sim$7%) and a corresponding increase in density.

Although there is a large variation in the degree of disintegration of the inclusions, transformation of inclusions to granite is very difficult to interpret. One of the most interesting features of the granitic rocks is that whereas bulk calcium contents are low (as are those of

the original metasediments) calcic cores are not uncommon in the granite plagioclases. Such cores are unlikely to from unless temperature conditions were sufficiently elevated or calcium was locally concentrated relative to sodium. It is unlikely that P—T conditions in Tumbarumba-Geehi district were elevated enough for large scale melting to occur, and it is thus conceivable that in the early stages of transformation to granite there has been local concentration of calcium.

The rather patchy zoning of the plagioclases may reflect a later introduction of sodium into the system of the granitic rocks. Certainly Na_2O is deficient in the metasediments compared with the granites. Vance (1965) favours magmatic resorption due to the release of confining pressure associated with emplacement as a major cause of patchy zoning in plagioclase. This factor cannot be overlooked here although there are no criteria directly supporting such an explanation. Subhedral or euhedral crystals do not display any obvious embayments while many of the patchy areas terminate along twin boundaries (see Plate 1) that are essentially low energy boundaries and should not be a general limitation in resorption. It is noteworthy that the Cooma-type granites do not display the degree of oscillatory or sharp normal zoning that is evident in the Khancoban, Mannus Creek and Dargals granites (Guy, 1964). These later bodies are interpreted as having migrated rather further from their position of origin than the Cooma-type granites, and hence are more likely to contain mineralogical features compatible with a history of such emplacement.

It is considered that the features display by the plagioclases in the Cooma-type granites are a direct result of local concentration of calcium followed by an influx of sodium into the granitic rocks. Such an influx of sodium may have taken place by diffusion in the solid state, or through the introduction of melt or solution. Either process would be aided by an increase in temperature conditions. The physical state of the granitic rocks during the introduction of sodium may conceivably have been that of a partial melt. This aspect will be discussed in more detail below (p. 19).

The nature of the alkali feldspars is of interest in the granitic rocks. Marmo (1967) contends that potash feldspars of most synkinematic granites are highly triclinic microcline, although potash feldspars that form porphyroblasts not uncommonly have lower triclinicities. Such feldspars are younger than other constituents in these rocks. He suggests that where there has been reasonably rapid introduction of potassium with little time for Al-Si ordering in the developing feldspars, orthoclase may be formed, whereas if the introduction rate is slow, ordering results and microcline will develop. The optical properties of the alkali feldspars in the Cooma-type granites of the present area indicate that the alkali feldspars are not highly triclinic and form " porphyroblasts " and thus they may have formed in a manner envisaged by Marmo. However, according to the scheme of Laves and Viswanathan (1967), the feldspars with low $\triangle$ values and high 2V may consist of domains with a high degree of order, i.e. the alkali feldspar are submicroscopically twinned. Thus $\triangle$ values for this suite may not be as low as indicated. The reason for the paucity of twinning in such feldspars is difficult to interpret and growth may be similar to that suggested by Marmo, i.e. growth is rapid so that the phase grew essentially as a monoclinic phase and not as " microcline " The influence of post crystallization deformation cannot be neglected here. Microcline with higher obliquity than orthoclase should twin less readily, however, this does not appear to be the case for most natural occurrences. Possibly the optically monoclinic feldspars of these granites have a high triclinicity and do not display a great deal of obvious twinning due to a rapid fall in temperature conditions after their formation, and the lack of any major deformation.

The K : Na ratio of the alkali feldspars in the Cooma-type granites is somewhat lower than that observed in other granitic suites of the Tumbarumba-Geehi district. This may be related to high degree of unmixing in the latter rock types and perhaps the Cooma-type granite alkali feldspars have developed when there was a relatively greater availability of sodium.

Marmo (1967) considers that many of the synkinematic granites have experienced addition of K and to a minor degree Na. Chemical data from the present investigation is more suggestive of introduction of sodium, as potassium contents of the granitic rocks (considering the composition of the inclusions as well) does not appear to differ markedly from that of the metasediments. Textural evidence indicates that the alkali feldspars and muscovite have formed somewhat later than other constituents, however, it is considered that such potassium is derived locally from the disintegration of muscovite and biotite in the inclusions, perhaps associated with a rise in temperature conditions. Stability of micas until late in the transformation process may be

responsible for survival (or perhaps production—see below) of cordierite in some of the granitic rocks.

It may be significant that the Mg : Mg+Fe+Mn ratio for the Cooma-type granites is slightly greater than that of an average psammopelitic metasediment (p. 8). This may imply that there has been a slight enrichment in Mg relative to Fe in the granitic rocks. The high value for this ratio in some of the analysed psammopelitic inclusions may be the result of such enrichment.

The transformation of inclusions to granitic material would require some addition of silica (see Fig. 2). This would be consistent with the expected reaction of micas (Si : O ratio ~1 : 3·3) transforming to feldspars (Si : O ratio ~1 : 2·7). Winkler (1967) suggests a reaction such as

2 biotite+6 sillimanite+9 quartz→2 K-feldspar component+3 cordierite+2 H_2O.

This reaction may in part be responsible for the paucity of quartz-rich or quartzo-feldspathic segregations immediately adjacent to mica segregations. The average bulk composition of the granite and biotite-rich inclusions would be markedly lower in SiO_2 than an average psammopelite. The transformation of inclusion to homogeneous granite would involve an increase in the number of anions associated with 100 cations (see Table 3) and hence an increase in volume or decrease in density. This may have influenced migration of granitic rocks to higher levels in the crust. The granites are in places surrounded by lower grade sections of the high grade zone or upper knotted schist zone rocks (Guy, 1969)—apart from where faulting has been operative. Such metasediments would have a similar specific gravity to that of the granites.

The bulk composition of the granitic rocks is such that few samples contain more than 80% Q+Or+Ab or fall in the low-temperature through of Tuttle and Bowen (1958). The normative ratio of Q : Or : Ab is approximately 45 : 30 : 25, although biotite clusters frequently have granular quartz associated with them, thus the Q content of portions of the granites capable of melting may be less than that indicated by the above ratio.

Von Platen (1965) has suggested that the Ab : An ratio is an important factor on the " minimum melting point " (Winkler, 1967) in the system Q–Ab–An–Or at $P_{H_2O}=2000$ bars. With increase in Ab : An ratio the " minimum melting temperature " decreases and is relocated towards the Ab corner, restricting the plagioclase field. A plot of some Cooma-type granites is noted in Fig. 3 with reference to this system. These analyses are presented on two Q–Ab–Or projections to illustrate the influence of Ab : An ratio on their crystallization history. Those rocks with low Ab : An ratio (<3·0) generally lie on the Ab side of the cotectic curve. Thus if such (or similar) rocks were melting plagioclase would be the last phase (neglecting biotite, etc.) to go into the melt. This may imply that any

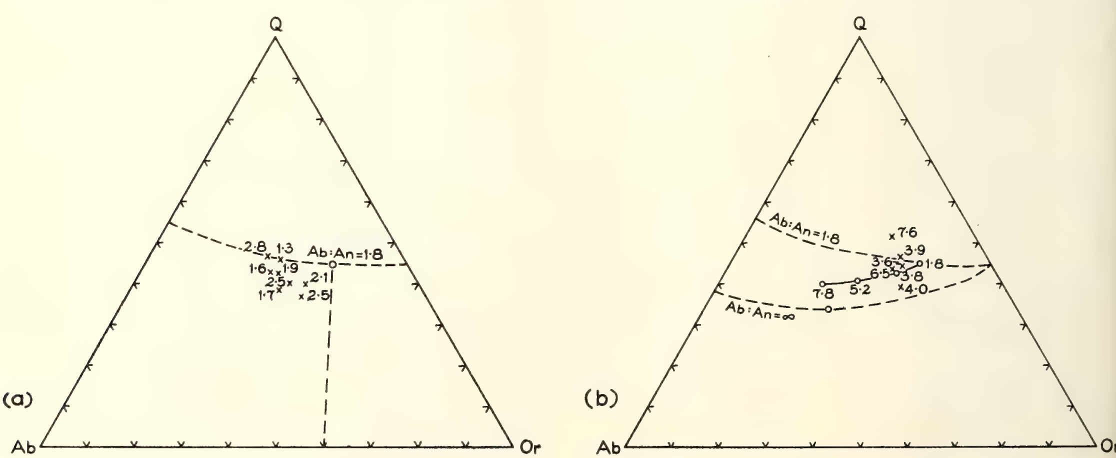

FIG. 3—Projections of sections through the system Q-Ab-An-Or-H_2O at P_{H_2O}= 2,000 bars. Points of " minimum melt " composition are indicated (○) and some cotectic curves for various Ab : An ratios. (After Von Platen, 1965.)

(*a*) Plot of Cooma-type granites (×) with Ab : An<3·0. The boundary between the plagioclase and K-feldspar fields (for Ab : An=1·8) is indicated.

(*b*) Plot of Cooma-type granites (×) with Ab : An>3·0. Figures against (×) symbols refer to the Ab : An ratio of the granites.

quartz-alkali feldspar-rich or quartz-rich segregations that may have developed in such granitic rocks through a segreation process, would be particularly susceptible to melt conditions.

If introduction of sodium followed some melting of rock types represented by Fig. 3a, there would be a marked change in the ratio of Ab : An (as the An contents are generally not large) as well as depressing the " minimum melting temperature ". The " minimum melt " and the cotectic line would be relocated towards the Ab corner. As such sodium introduction would not greatly change the amount of Ab relative to Or and Q, the plot of the granitic rocks on the diagram Q–Ab–Or would not be significantly altered.

If associated with sodium introduction, there was breakdown of micas (see p. 18) and perhaps some incorporation of quartz-rich segregations (*cf.* Fig. 2), the bulk composition of the granitic phases would be relocated away from the Ab corner. Thus the distribution of granitic rocks noted in Fig. 3b—i.e. those with high Ab : An ratio—may be explained by such a sequence of events. It is interesting that in the latter case those rocks with high Ab : An ratio, would lie on the Q side of the cotectic and thus quartz would be the last phase to melt. Thus fluctuation in temperature, pressure, breakdown of biotites, or introduction of Na would have a marked influence of the phase(s) in equilibrium with the melt. The patchy zoning of the plagioclases may be a direct result of such a crystallization history.

Some recent investigations by Weill and Kudo (1968) have thrown some doubt on the work of Von Platen. The former authors suggest that the Q–Or–Ab system does not have a unique melting point or a unique composition of initial melt. This does not detract from the suggestion by Winkler (1967) that for any Ab : An ratio there is still a minimum melting point for the system. Some doubt exists as to whether the minimum melting points determined by Von Platen is the absolute minimum in the system Q–Ab–An–Or for a fixed Ab : An ratio. Weill and Kudo's suggestion that there is a unique melting point for a given Ab : Or ratio may not be particularly significant for the Cooma-type granites considering that the development of such rocks is related to breakdown of the micas. If it is assumed that Von Platen's experimental study does suggest a trend for minimum melt composition with variation in Ab : An ratio, a feasible theory may be proposed for the development of the Cooma-type granites.

The sequence of events envisaged in the formation of these granites may be summarized as :

1. Very high grade metamorphism of a sequence of rocks with a compositional range close to that of a psammopelite. The metamorphism involves a decrease in volume with increase in grade. The principal phases would be quartz, micas (mainly biotite) and minor, but rather calcic plagioclase. Calcium and magnesium may have been locally concentrated at this stage. Some segregation of constituents may have taken place producing quartz-rich or quartzo-feldspathic-rich, and mica-rich sections. Diffusion would presumably have been the main process involved in migration of material. Melt is considered not to have been of much significance at this stage.

2. Introduction of sodium, possibly by local concentration from the metasediments, but more likely by diffusion from lower levels in the crust. Such diffusion of sodium would be favoured by elevated temperatures. Both controls (elevated temperature and Na introduction) would be conducive to the production of a partial melt and migration of the cotectic line of the system Q–Ab–An–Or–H_2O towards the Ab corner. Breakdown of micas, also compatible with increase in temperature would favour a change in the phase co-existing with the melt. Such conditions are considered to have been a significant factor in producing the patchy zoning in the plagioclase and the production of alkali feldspars in granitic rocks. The reactions involved in this transformation to granite may have resulted in an increase in volume (*cf.* Table 3) and a decrease in density. This may have been a factor in the migration of Cooma-type granites to higher levels in the crust. It is possible that these rocks have been annealed after emplacement with a significant modification of their textures. The cell structures noted in the quartz grains and some undulatory character of the feldspars may have developed through such a process as annealing.

Pidgeon and Compston (1965) have suggested an age of 415 ± 12 m.y. for the Cooma granite and the surrounding high grade metamorphics at Cooma. More distant greenschist facies rocks are reports to have an age of 460 ± 11 m.y. These authors indicate there is no evidence to suggest any metamorphism later than that developed in the high grade zone and propose that the Cooma granite is locally derived from rocks in the high grade zone. In the Khancoban area (Guy, 1969) there is evidence that the regional metamorphism is multiple in

character and that this is discernible only in the higher grade metamorphics. Pidgeon and Compston have not discussed fully the significance of similar ages obtained for the Cooma granite and a section of the Murrumbidgee batholith.

Acknowledgements

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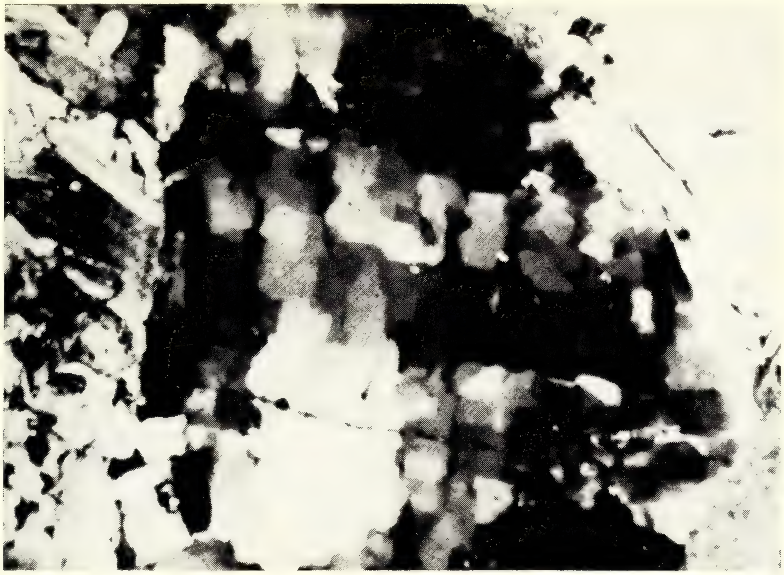

PLATE 1 (*a*)

Cell structure in a quartz grain from the Corryong Granite (spec. 21809). Note the polygonal arrangement of the small domains. Crossed nicols, $\times 120$.

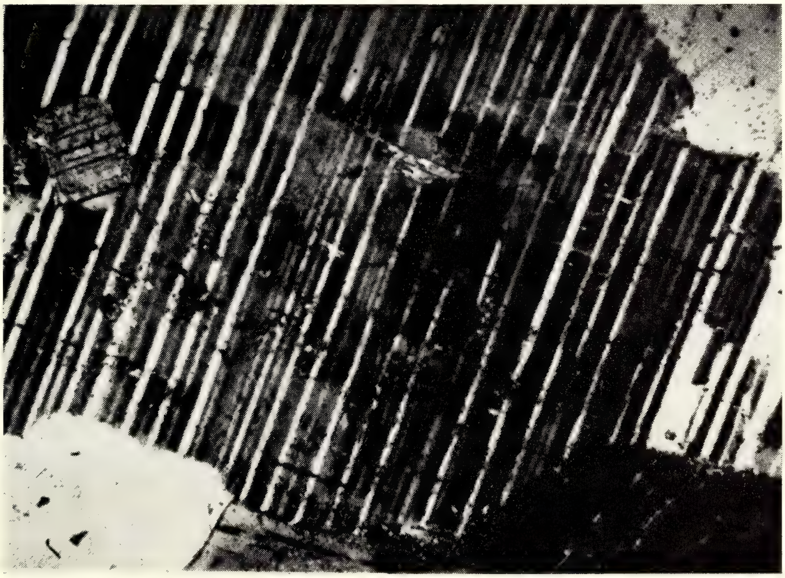

PLATE 1 (*b*)

Section of a plagioclase grain displaying patchy zoning, from the Corryong Granite (spec. 21842). This zoning is evident only near the extinction positions. Crossed nicols, $\times 45$.

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The Nature and Occurrence of Heavy Minerals in Three Coastal Areas of New South Wales

J. R. Hails[1]

Abstract—A detailed mineralogical study has been undertaken in an attempt to determine the sources of heavy minerals in three areas of New South Wales. The areas studied are Twofold Bay and neighbouring South Coast districts between Pambula and Disaster Bay, Broken Bay near Sydney, and the Mid-North Coast between Port Macquarie and Grassy Head. The percentage variations of different minerals in both Pleistocene and Holocene sediments have been evaluated. Diagnostic heavy minerals have been traced in some barrier and dune sands, and it is believed that these were transported shorewards during marine transgressions accompanying interglacial periods, and reworked locally by longshore drifting. Most of the minerals in the unconsolidated deposits on the east Australian coast can be described as *polygenetic* because they have been derived from various sources, and their origin is very complex in relation to both time and place.

Introduction

(a) *The Nature of the Problem:*

The barriers[2] and dunes on the New South Wales coast are composed of sediments that were reworked during Pleistocene fluctuations of sea-level and during the post-glacial or Holocene marine transgression. Such deposits can therefore be described as *polygenetic* since they have been derived from various sources and their origin is very complex in relation to both time and place. The writer has analyzed Pleistocene and Holocene sediments in an attempt to determine the sources of the heavy minerals in three coastal areas of New South Wales. The areas, which differ geologically and physiographically, are Twofold Bay and neighbouring South Coast districts between Pambula and Disaster Bay (Figure 1), Broken Bay near Sydney (Figure 2), and the Mid-North Coast between Port Macquarie and Grassy Head (Figure 3).

The origin and distribution of heavy mineral beach sands in New South Wales and south-eastern Queensland have been mentioned briefly in technical reports by Gardner (1955), Whitworth (1956) and Connah (1962). Jones (1946) and Beasley (1948, 1950) have discussed the concentration of heavy minerals in beach deposits. Culey (1933, 1939) studied the heavy mineral assemblages of the Narrabeen and Hawkesbury Sandstones. However, no detailed investigations have been made to determine the relationship between heavy mineral concentration and longshore drifting, aeolian activity and the shoreward movement of material from the sea floor during marine transgressions.

(b) *The Physiography and Geology of the Areas:*

Dual barrier systems, composed entirely of quartzose sand and separated by swamps and lagoons, have been mapped on several sectors of the New South Wales coast. These have been termed Inner (Pleistocene) and Outer (Recent) Barriers by Langford-Smith and Thom (1969).[3]

The Holocene (Recent) barriers developed across the mouths of drowned river valleys to enclose estuarine lagoons partly or completely from the sea after 7000 B.P. (before the present), at a time when the rate of the post-glacial or Holocene rise of sea level slowed down appreciably (Hails, 1968). The barrier systems of the Central and South Coast of New South Wales are not as clearly represented by Pleistocene and Holocene components as those on the Mid-North Coast which border large fluvial-deltaic

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[2] The term *barrier* applies to littoral sand accumulations—either beaches, spits or islands—that stand permanently above high-tide level and enclose lagoons or shallow bays. Barriers are usually characterized by multiple beach ridges, but a few are comprised of a single ridge. A few beach ridge systems, for example, the Umina-Woy Woy system in Broken Bay, are not separated from a bedrock hinterland by large coastal lagoons.

[3] The terms Outer (Recent) Barrier and Inner (Pleistocene) Barrier will be used in the same context as originally defined by Langford-Smith and Thom (1969).

plains. This is because former broad protected bays of the North Coast, and an abundant supply of sand from large rivers, favoured the development of wide barriers, while the more rugged embayments and lack of large rivers on the Central and South Coast did not. The limited extent to which the estuarine lagoons on the South Coast have been filled by fluvial deposits also reflects the size, discharge and sediment yield characteristics of the river catchments (Bird, 1967).

Twofold Bay (Figure 1) and adjacent areas are composed of strongly folded and faulted Devonian strata, with Ordovician metamorphic rocks and Tertiary basalts (Brown, 1930, 1933 ; Steiner, 1966). The sedimentary rocks around Twofold Bay are of variable composition, and are associated with rhyolites, basalts and dolerites. Unconsolidated sands and gravels of varying thickness which directly overlie the Devonian rocks have been designated Tertiary (Hall, 1957).

Twofold Bay, one of the largest embayments on the South Coast, is actually a succession of smaller bays, with bayhead beaches, which are separated by headlands and small promontories. The Boyd Town barrier system is the largest of its kind inside the bay, and is situated between the Nullica River and Boyd Town Creek. It consists of a series of abandoned beach ridges with intervening swales and is backed by degraded sea cliffs. Eden barrier spit impounds Curalo Lake which occupies the drowned valleys of Bellbird Creek and adjacent coastal streams. Whale Beach barrier encloses the Towambah (Kiah) estuary and north of Twofold Bay, Pambula barrier spit partly encloses Merimbula Lake.

Broken Bay (Figure 2) is part of the dendritic drowned valley of the Hawkesbury River, and is dominated by vertical cliffs cut in resistant, almost horizontally-bedded, Hawkesbury and Narrabeen sandstones of Triassic age. Lenticular layers of shale are interbedded with the sandstones which are characterized by major systems of vertical joints (David, ed. W. R. Browne, 1950). Tertiary dykes and sills have been reported in a few coastal sections. Patonga Beach is a sand barrier which almost completely encloses the mouth of Patonga Creek in Brisk Bay, whilst Pearl Beach barrier originally developed across the mouth of a small embayment.

The Umina-Woy Woy barrier is the largest depositional feature in Broken Bay. It consists of a series of abandoned beach ridges aligned parallel to the shoreline. There is some evidence to suggest that this barrier may be composed

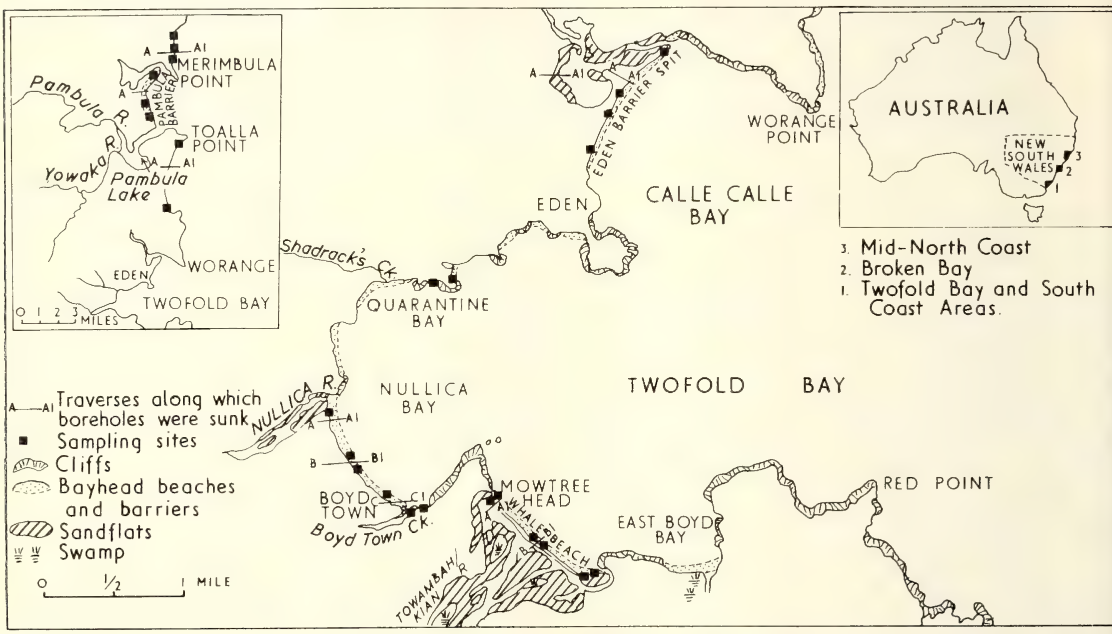

FIG. 1—Twofold Bay and adjacent South Coast areas. Inset map of Australia shows location of the three study areas in New South Wales.

of Pleistocene as well as Holocene sediments (Hails, 1969), in contrast to Pearl Beach and Patonga Beach which are Holocene barriers.

The Mid-North Coast (Figure 3), is characterized by zeta-curved or arcuate bays which are flanked by resistant bedrock headlands. Some of the headlands are mantled with deeply podzolized Pleistocene cliff-top dunes that stand between 100 and 400 feet above present sea level.

According to Voisey (1934), the headlands are composed mainly of sandstones, tuffs, mudstones, claystones and shales with minor conglomerate bands. These deposits, termed the Kempsey Series, are believed to be of Permian age. The hinterland of the Mid-North Coast forms part of the New England Plateau which is composed predominantly of Palaeozoic rocks, and Tertiary basalts. The Macleay is the largest river on the Mid-North Coast, and its headwaters occupy valleys which have been incised into the New England Plateau. No deltas have been built seaward of the modern coast in northern New South Wales. Instead sedimentation and alluviation have taken place between an ancient bedrock coastline and the dual barrier systems, resulting in the construction of fluvial-deltaic plains.

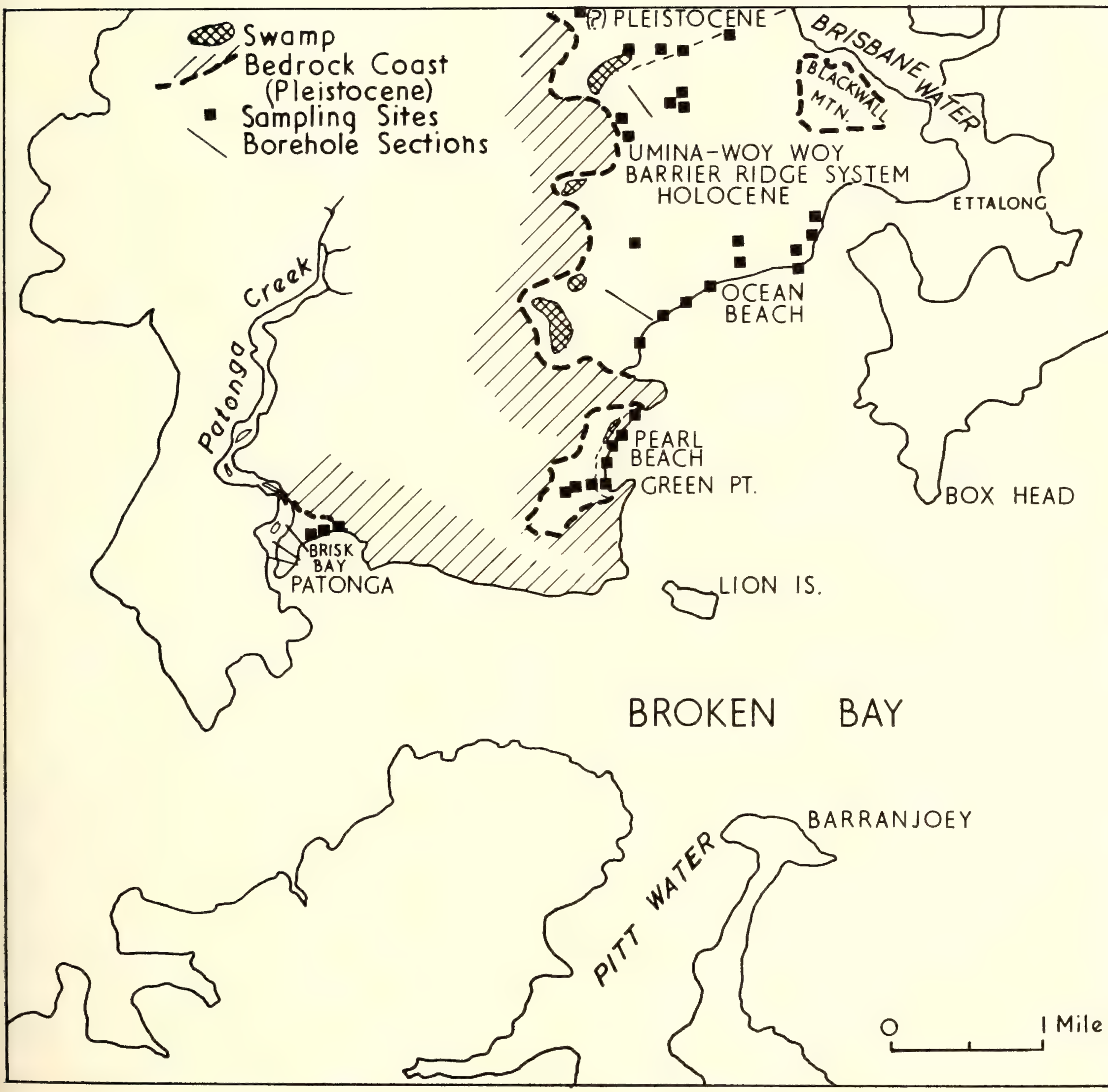

Fig. 2—Map to show the location of barriers in Broken Bay.

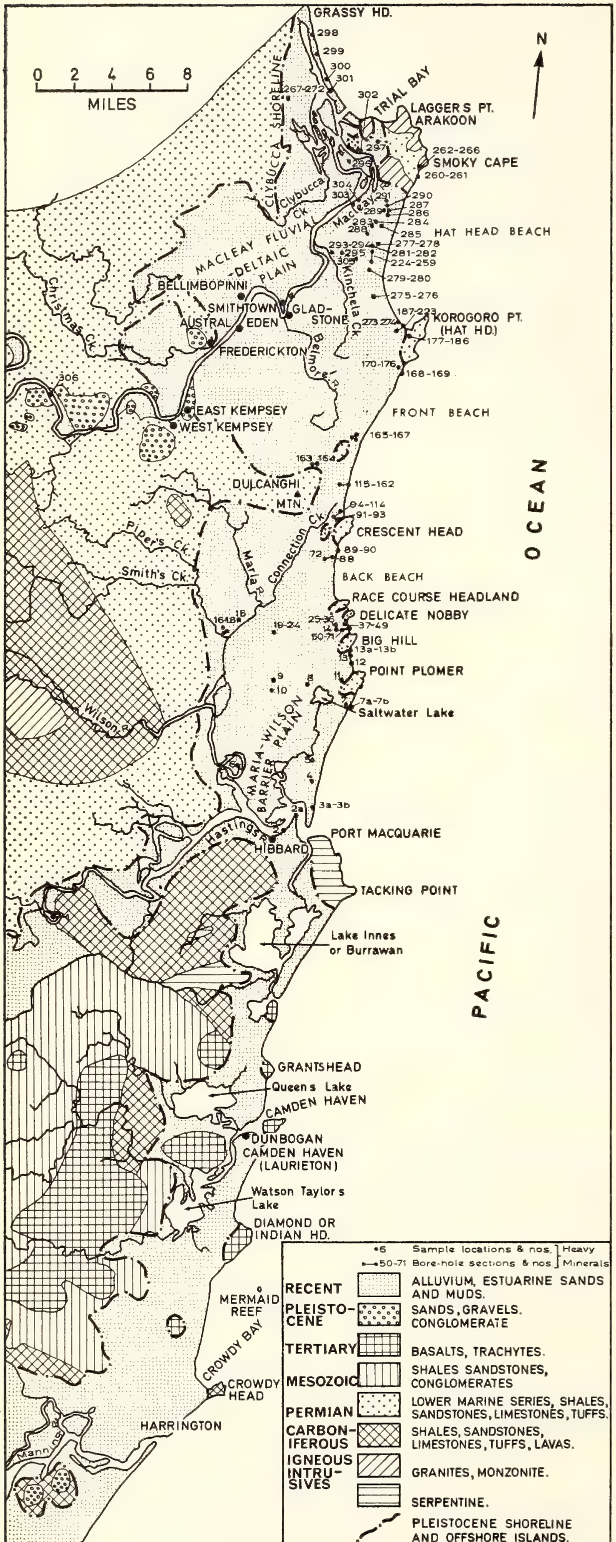

Fig. 3—Locality map of the Mid-North Coast showing location of heavy mineral samples. Geology based on the work of Voisey.

(*c*) *The Aims of the Study:*

The purpose of this study has been:

1. To trace the sources of the heavy minerals. Sources can be sub-divided into: indirect sources, such as material being reworked from immediately offshore, and direct sources, whereby minerals are derived from eroded adjacent cliffs and headlands.

2. To evaluate the percentage variation of the different minerals in Pleistocene and Holocene barrier and dune sands in order to determine whether there is any significant difference with age. An assessment has been made of the chemical stability of the heavy minerals and their resistance to abrasion. The percentage concentration of heavy minerals in barrier and dune sands has been examined in an attempt to assess the transporting effect of wind and wave action.

3. To compare the heavy minerals collected in the inland drainage basins of the Hastings and Macleay Rivers with those in coastal deposits to see if any diagnostic minerals have been transported alongshore. Also, to ascertain whether heavy minerals by-pass river, creek and lagoonal outlets, and are transported around headlands or promontories by littoral currents.

Because serpentine outcrops on the Mid-North Coast south of the Hastings River, the area between Port Macquarie and Grassy Head has been studied in detail (Figure 3). The writer considered that a few diagnostic minerals derived from serpentine rocks might be transported around Point Plomer, Big Hill, Delicate Nobby and other headlands flanking the arcuate bays.

4. To determine the roundness values of the heavy minerals in order to ascertain, if possible, the relationship between roundness and environments of deposition in the three physiographical areas.

Field and Laboratory Procedures

Barrier, dune (including cliff-top dune), fluvial and offshore neritic environments were sampled. Beach samples were collected just below the swash line of high water (HWM) and approximately at Bascom's (1951) "reference point" which is the part of the beach subjected to wave action at the mid-tide stage. Although mid-tide refers to a level half way between the previous high-tide and the succeeding low, the inter-tidal zone varies from its predicted position

according to local conditions at the time of sampling. Barrier and dune samples were collected at one-foot intervals from boreholes sunk along surveyed transects across the barriers and deltaic plains. Lines of section were approximately perpendicular to the beach and extended from low water mark to a degraded coastline behind either the barriers or deltaic plains. No samples were collected below the water table because of the risk of contamination by material washed into the boreholes.

Samples collected from the swamps and deltaic plains which contained a high content of silt and clay were analyzed by the hydrometer method of Bouyoucos (1936).

All sand samples were oven dried and a 100 gm. sample split was sieved through a set of B.S.S. 8-inch sieves at the $\frac{1}{4}(\Phi)$ phi interval on a Ro-Tap machine for 15 minutes. The fractions retained on the sieves were weighed on a Mettler Precision Balance to 0·01 gm. and amounts smaller than 1 gm. were weighed to 0·001 gm. Tests showed that very few, if any, heavy minerals occurred in the −60 mesh (0·251 mm.) grade of sand. Therefore, only the −60+200 mesh (0·251–0·074 mm.) fractions were retained for heavy mineral analysis.

The light and heavy mineral fractions of a 5-gram sample split of each sample were separated in bromoform (S.G. 2·90) by using a centrifuge. The heavy residue was weighed and recorded as a weight per cent. A part of the heavy mineral residue, obtained with a micro-splitter, was mounted in Canada balsam for microscopic examination and grain counts. In addition, microscope slides were made of the light-heavy, and rutile-zircon-ilmenite fractions of samples specially treated at Mineral Deposits Laboratory, Crescent Head, N.S.W. The percentage number of each mineral in an individual sample was determined by using a mechanical stage and by counting 300 grains. Dryden (1931) suggested that 300 counts is an optimum number, and also that the accuracy of the counts increases as the square root of the number of grains counted. The heavy mineral fractions of six samples collected from the Macleay and Hastings Rivers (Numbers 1, 2–2a, 3a–3b, and 306, Figures 3 and 8) were separated into magnetic and non-magnetic fractions by using a Model L-1 Frantz Isodynamic Separator.

The unmounted portion of the heavy residue of each sample was examined under a binocular microscope, and roundness analyses were conducted by following the method of Shepard and Young (1961). They modified the scale developed by Powers (1953) by introducing "pivotability", whereby grains were viewed under a binocular microscope and compared visually with a scale of roundness (pivotability) which is divided into six categories. In order to prevent operator bias the samples were renumbered, so the writer was unaware of their location. 100 grains were counted in each sample.

The accuracy of heavy mineral analyses, depending upon errors in both field sampling and laboratory studies, has been discussed by Dryden (1931), Krumbein and Rasmussen (1941), Manning (1953) and other workers. Rubey (1933) stated that large variations in the relative abundance of various minerals will be found in different grain sizes of the same sample. On the other hand, Van Andel (1955) and Poole (1958) concluded that only in special cases is it necessary to study various size fractions separately. In the light of more recent work by Carroll (1957) the writer considers that the method employed in this study has been valid and has not impaired the final results. Carroll (*op. cit.*) pointed out that procedural errors can probably safely be neglected from the mineralogical point of view when minerals have been subjected to previous sorting and sedimentation processes, even though it is recognized that certain minerals tend to occur in larger or smaller grain sizes than others.

Heavy Mineral Occurrences

(*a*) *South Coast Samples:*

Tourmaline, amphiboles (chiefly hornblende), pyroxenes (chiefly titan-augite and diopsidic augite), members of the epidote group, and the opaques are the most common minerals in the South Coast beach and barrier samples. The opaque minerals and tourmaline constitute 70 and 80 per cent respectively of the heavy fraction in the Pambula and Eden barrier sands, whereas these minerals plus the amphiboles and epidote comprise 86 per cent of the total heavy mineral assemblage in the Boyd Town samples. In addition, andalusite, zircon, enstatite, topaz, rutile, sphene, garnet (colourless and pink), monazite and other minor constituents have been identified. With the exception of andalusite, the other minerals do not occur in sufficient quantities to be of importance. The variation in percentage of these minerals is shown in Figure 4, and listed in Tables 1 and 2. Table 1 compares the heavy mineral concentrates of barrier and dune sands in the three study areas.

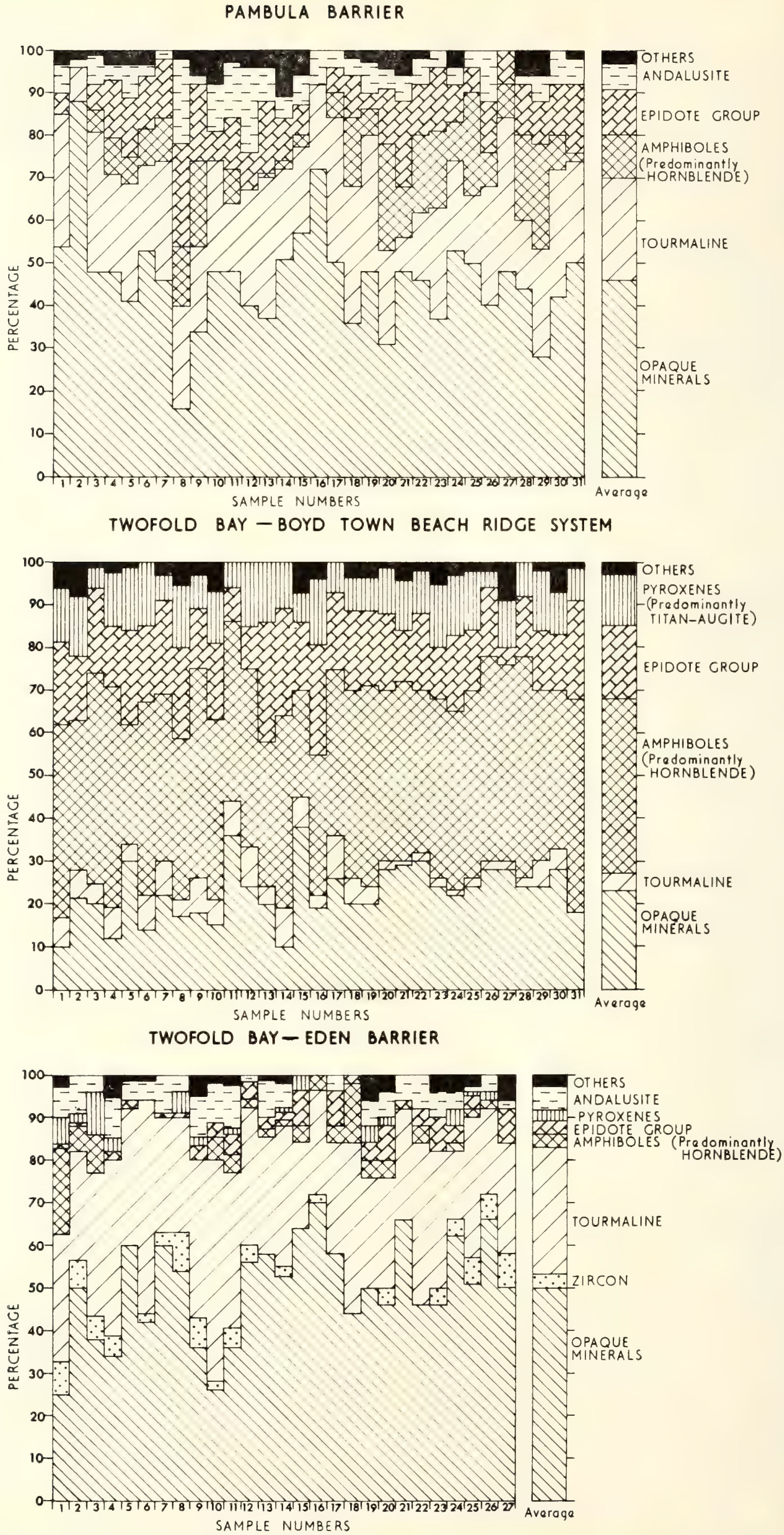

FIG. 4—The percentage occurrence (by number) of heavy minerals identified in South Coast barrier samples. The average composition is also shown. Sample numbers refer to sections and sampling sites shown in Fig. 1.

TABLE 1

Average Percentage Occurrence (by Number) of Heavy Minerals in Some Mid-North Coast, Broken Bay and South Coast Barrier and Dune Samples

Locality/ Environment	Mineral																	
	Rutile	Zircon	Tourmaline	Monazite	Garnet	Apatite	Staurolite	Kyanite	Epidote Gp.	Amphiboles (chiefly Hornblende)	Andalusite	Topaz	Sphene	Pyroxenes (chiefly Augite)	Hypersthene	Enstatite	Picotite	Spinel
Mid-North Coast:																		
Delicate Nobby	21·23	16·29	50·60	0·21	2·08	0·02	1·25	0·08	1·93	0·27	4·08	0·19	0·02	0·21	0·27	0·95	0·32	—
Back Beach (inner barrier) ..	24·53	42·64	26·67	0·60	0·12	—	1·06	—	0·06	—	3·23	0·06	0·12	0·18	—	0·06	0·67	—
Killick Creek, nr. Crescent Head (inner barrier)	32·51	37·02	24·95	0·08	0·08	—	1·16	0·08	0·25	—	3·75	0·12	—	—	—	—	—	—
Front Beach (outer barrier) ..	15·77	17·41	53·73	0·40	0·90	0·04	1·50	0·21	1·64	1·18	5·00	—	0·37	0·37	0·41	1·03	0·04	—
Hat Head (outer barrier) ..	14·54	8·00	62·38	0·60	2·00	0·35	1·18	0·16	2·48	0·18	4·94	0·37	0·13	—	0·22	2·27	—	0·20
Hat Head (inner barrier) ..	9·72	32·40	52·69	—	0·06	0·11	1·08	—	0·28	—	3·60	0·06	—	—	—	—	—	—
Hat Head (cliff-top dunes) ..	17·90	35·70	42·10	—	—	0·40	0·90	—	0·40	—	2·40	0·20	—	—	—	—	—	—
Smoky Cape (cliff-top dunes) ..	14·20	40·40	44·20	—	—	—	—	—	—	—	1·20	—	—	—	—	—	—	—
Front Beach (transgressive dunes)	22·28	27·42	43·59	—	—	—	0·71	—	—	—	6·00	—	—	—	—	—	—	—
Clybucca shoreline	24·53	71·03	3·83	—	0·16	—	0·16	—	0·16	—	0·33	—	—	—	—	—	—	—
Maria - Wilson barrier plain ..	39·00	38·69	19·83	—	—	—	0·83	—	0·16	—	1·16	0·33	—	—	—	—	—	—
Broken Bay:																		
Umina-Woy Woy beach ridge system; Pleistocene (?) samples	36·95	26·85	24·71	1·80	0·09	—	—	—	1·83	3·68	3·68	0·02	—	0·32	0·07	—	—	—
Holocene samples	30·08	30·62	22·96	0·55	0·96	—	—	—	6·44	4·88	3·11	—	—	0·22	0·11	—	0·07	—
South Coast:																		
Boyd Town beach ridge system ..	0·09	0·51	6·35	—	0·49	0·03	—	—	21·87	54·00	1·29	0·35	0·22	14·19	—	0·61	—	—
Eden barrier spit	0·55	6·66	64·99	0·52	1·74	—	—	—	6·74	4·26	10·49	0·44	0·07	3·33	0·14	0·07	—	—
Pambula barrier spit	0·45	1·55	46·20	0·19	1·70	—	—	0·06	19·23	16·35	12·42	0·40	0·13	0·64	—	0·68	—	—

(*b*) *Broken Bay Samples:*

The most abundant heavy minerals for all samples are the opaques, rutile, zircon and tourmaline (Figure 5; Tables 1 and 3). Together, they generally constitute almost 90 per cent of the heavy minerals in the Broken Bay barrier and beach sands, and offshore sediments. Other minerals present in significant quantities include those of the amphibole (chiefly hornblende) and epidote groups, andalusite and monazite. Minor constituents in order of decreasing occurrence are garnet (colourless and pink varieties), pyroxenes (chiefly augite), hypersthene, topaz, picotite, staurolite, sphene, spinel, enstatite and apatite (Tables 1 and 4).

TABLE 2

Average Percentage Occurrence (by Number) of Heavy Minerals in South Coast Barrier Samples

(Percentage taken to nearest whole number)

Mineral	Eden Barrier Spit (Twofold Bay)	Boyd Town Barrier Beach Ridge System (Twofold Bay)	Pambula Barrier Spit
Opaques (magnetite, ilmenite, leucoxene, haematite, limonite)	50	23	46
Zircon	3	0*	0*
Tourmaline	30	5	24
Rutile	0*	0*	0*
Andalusite	5	0*	6
Amphiboles (chiefly hornblende)	3	41	10
Pyroxenes (chiefly titan-augite and augite)	3	11	0*
Epidote	3	17	11
Others	3	3	3

* Included in 'Others' as percentage occurrence in samples is less than 3%.

(*c*) *Mid-North Coast Samples:*

The minerals identified in the Mid-North Coast samples can be divided into three distinct groups: opaque minerals, which include ilmenite, magnetite and leucoxene; common detrital minerals, such as zircon, tourmaline and rutile, and those designated "others", of which staurolite, andalusite, garnet, kyanite, epidote, picotite, hypersthene and spinel are considered to be the important diagnostic minerals. The first two groups together constitute more than 85 per cent of the heavy minerals present in the sedimentary environments that were sampled.

TABLE 3

Average Percentage Occurrence (by Number) of Heavy Minerals in Broken Bay Barrier Samples

Mineral	Umina (Ocean Beach)-Woy Woy Beach/Dune Ridge System		Pearl Beach Barrier Numbers	
	Holocene	Pleistocene (?)	1–7*	1–93*
Opaques (magnetite ilmenite, leucoxene, haematite, limonite)	36	44	31	21
Zircon	18	16	29	31
Tourmaline	15	12	6	6
Amphiboles	2·50	1·78	—	—
Epidote group	3·75	—	—	—
Rutile	20·50	22·25	33	40
Andalusite	2·25	2	—	1
Others	2	1·97	1	1

* See Figure 5.

TABLE 4

Percentage Occurrence of Minerals in Pearl Beach and Patonga Samples

(Percentage occurrence is not expressed by numbers per sample, but number of times the minerals have been found in the total number of samples analyzed. For example, Andalusite has been found in 38 of the 100 Pearl Beach barrier samples)

Mineral	Pearl Beach Barrier (100 samples)	Patonga Barrier Spit (217 samples)	Patonga Offshore (70 samples)
Monazite	31	18	27
Garnet	10	8	6
Apatite	—	1	—
Staurolite	2	<1	—
Epidote group	17	30	54
Amphiboles (chiefly Hornblende)	21	20	54
Andalusite	38	44	51
Topaz	—	4	7
Sphene	1	—	1
Pyroxenes (chiefly Augite)	2	9	11
Hypersthene	6	3	4
Enstatite	—	1	—
Picotite	6	2	1
Spinel	—	<1	—

Minerals are arranged with the least persistent mineral last. As picotite and spinel are not shown in the Order of Persistence Table (Table 5B), they have been placed below the dashed line.

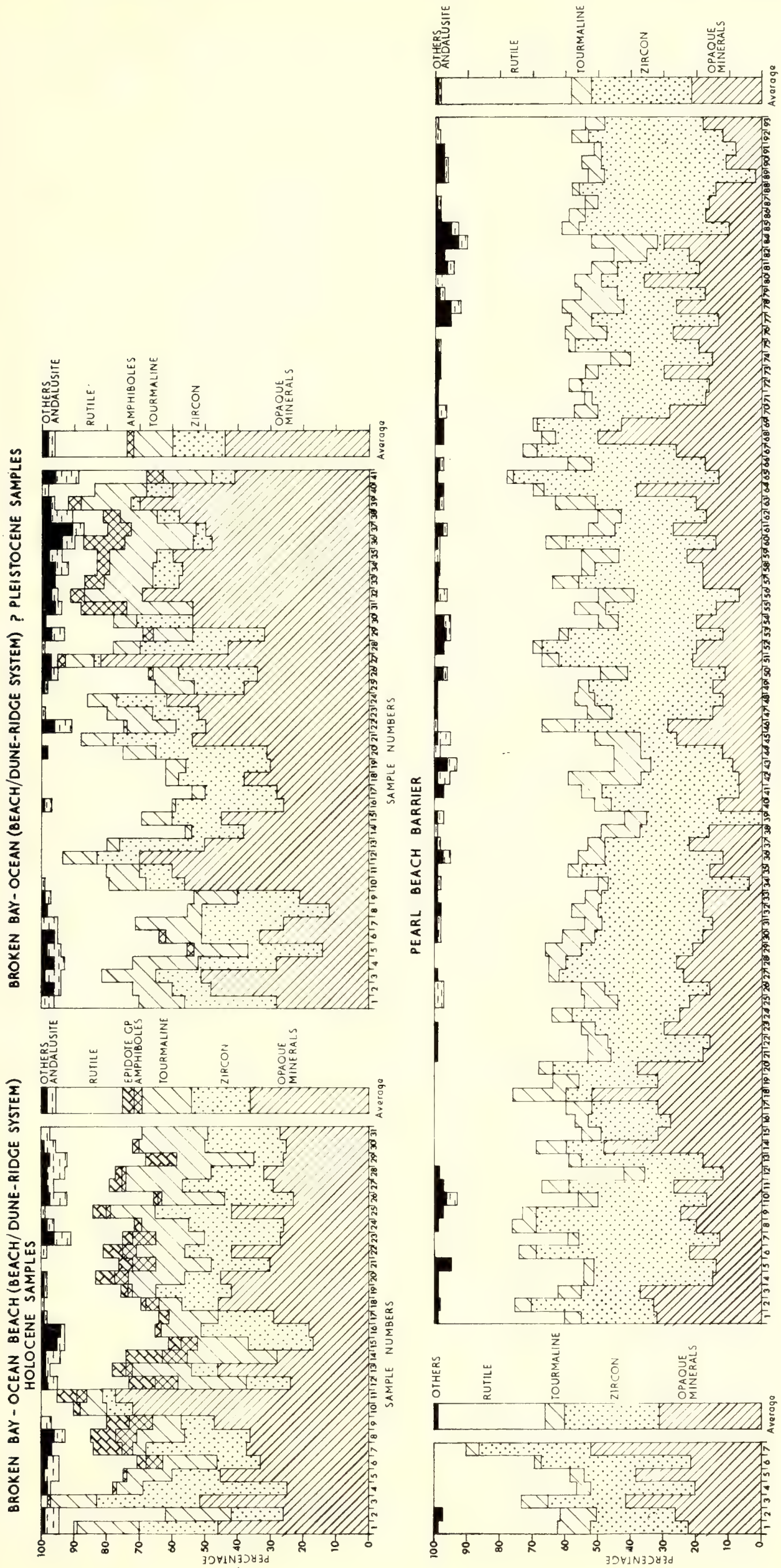

FIG. 5—The percentage occurrence (by number) of heavy minerals identified in Broken Bay barrier samples. Sample numbers refer to sections and sampling sites shown in Fig. 2.

Small quantities of monazite, apatite, amphiboles (hornblende), topaz, sphene and pyroxenes (chiefly augite) have been identified. The percentage occurrence (by number) of all these minerals is shown in Figures 6 and 7. The percentage range and mean of each mineral are plotted in Figure 7 which also shows the non-opaque heavy mineral composition of Pleistocene and Holocene barrier and dune samples. The variation in percentage of all the minerals, except the opaques, is listed in Table 1.

Discussion of the Results

(*a*) *South Coast Samples:*

The same minerals are common to practically all samples, but their percentage occurrence (by number) varies significantly in the Twofold Bay deposits. These variations can be partly explained by the different types of rock in the immediate vicinity of Twofold Bay. Shadrack's Creek and the Nullica River, which flow into Nullica Bay, drain catchments of unconsolidated Tertiary (?) deposits, Devonian rhyolites, dolerites and felsites, and Ordovician metamorphic rocks. In contrast, Bellbird Creek, which enters Curalo Lake (almost entirely isolated from Calle Calle Bay by Eden barrier spit), drains a catchment of predominantly sedimentary rocks—sandstones, siltsones, shales and quartzites. Therefore, it is not surprising that the analyses reveal significant differences in the percentage occurrence of epidote, titan-augite and the amphiboles in the barrier and beach sands of Nullica and Calle Calle Bays. For example, titan-augite is almost four times, epidote six times, and the amphiboles fourteen times more abundant in the Boyd Town barrier sands than in the Eden barrier samples (Table 2).

The percentage occurrence of hornblende is somewhat anomalous. Titan-augite and diopsidic augite, the most abundant of the pyroxenes identified, appear to have been derived locally. Probably, the former was derived from either the basalts or dolerites, in which it often replaces common augite, whilst the latter possibly originated in the rhyolites, such as the potash type at Eden. The comparatively small percentages of rutile, zircon and other minor

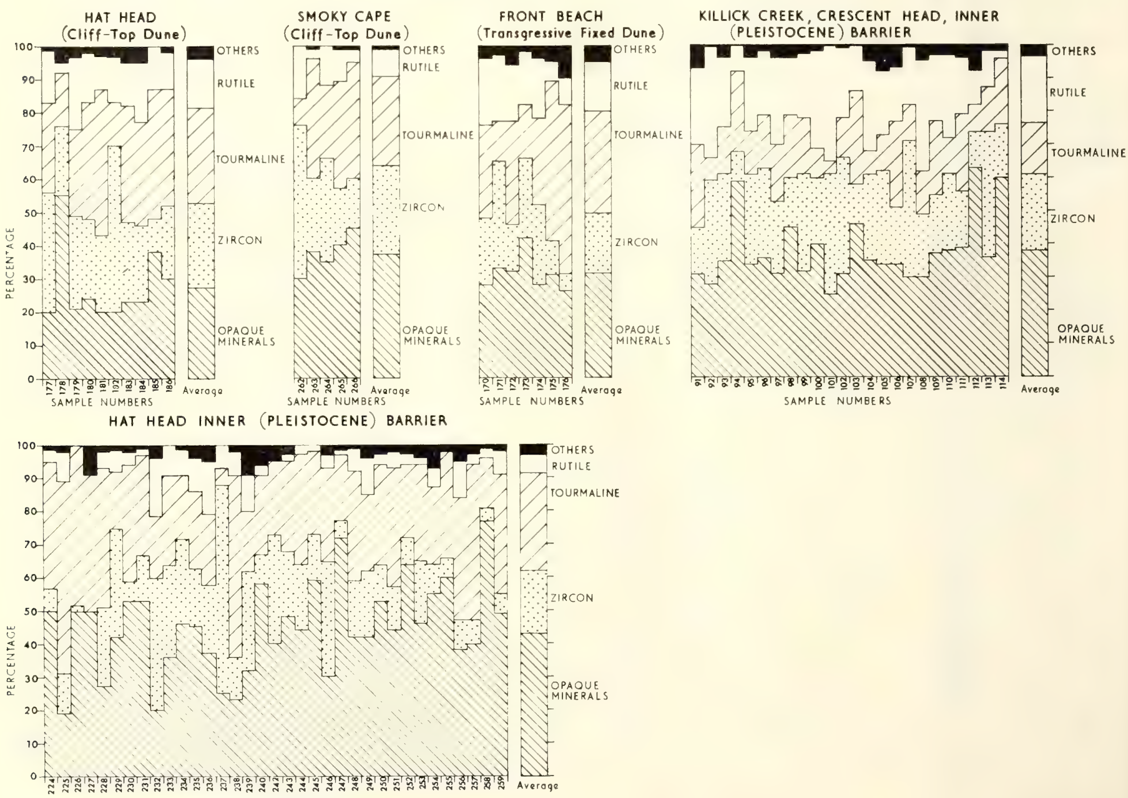

FIG. 6—The percentage occurrence (by number) of heavy minerals identified in Mid-North Coast barrier and dune samples.

(FIG. 6 — *continued.*)

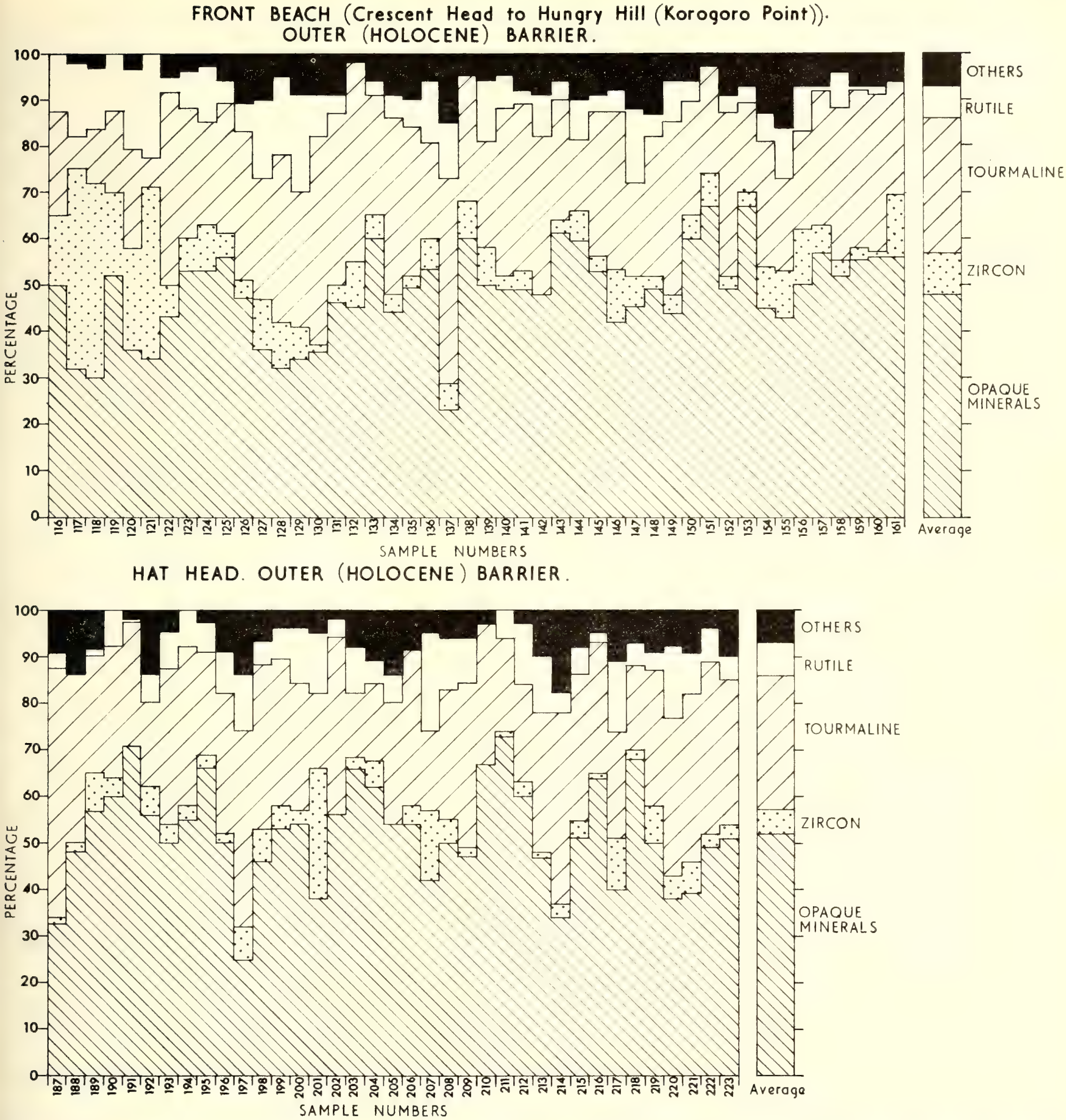

FIG. 6—The percentage occurrence (by number) of heavy minerals identified in Mid-North Coast barrier and dune samples.

constituents also seem to indicate the composition of the rocks being eroded in the Twofold Bay hinterland.

The variation in the percentage occurrence (by number) of the respective heavy minerals provides some evidence to discount the possibility that sediments, deposited within the smaller embayments of Twofold Bay, are transported around headlands. It is concluded, therefore, that the sediment yield, derived from the weathered rocks of the Twofold Bay hinterland and delivered to the nearshore zone by way of the rivers, is reworked and redeposited locally by wave action to nourish the barriers and bayhead beaches. This supply of sediment is supplemented, on a limited scale, by material derived from the erosion of adjacent headlands. Fine-grained material carried a short distance offshore, also appears to be transported shoreward subsequently without drifting around the headlands that separate the smaller embayments.

Additional evidence supporting the argument that sediments carried into Nullica Bay are not transported around neighbouring headlands can be found in the roundness values of the heavy minerals from the Boyd Town barrier system. Generally, these values are lower than those of the samples collected from Whale Beach barrier. It can be seen from Figure 9 that the heavy minerals from the Eden and Pambula barriers are particularly well rounded when compared with those from the Boyd Town barrier system. Most of the smaller bays inside Twofold Bay are low-energy wave environments compared with the exposed sectors of the far South Coast. Therefore, in the smaller embayments like Nullica Bay, it is unlikely that minerals would be altered appreciably by abrasion in the surf zone. But it would be presumptuous, considering some of the points made later about the roundness values of the Mid-North Coast minerals, to make conclusive statements about the Boyd Town samples. Fairly sub-angular grains, derived from the various catchments, might undergo minimal abrasion only before being deposited in the nearshore zone, because they are moved relatively short distances by the small coastal rivers.

Plates 1D–1F, which show some heavy mineral grains from the Boyd Town, Whale Beach and Pambula barriers, illustrate the marked contrast between the angular and sub-angular grains of the South Coast samples and the comparatively

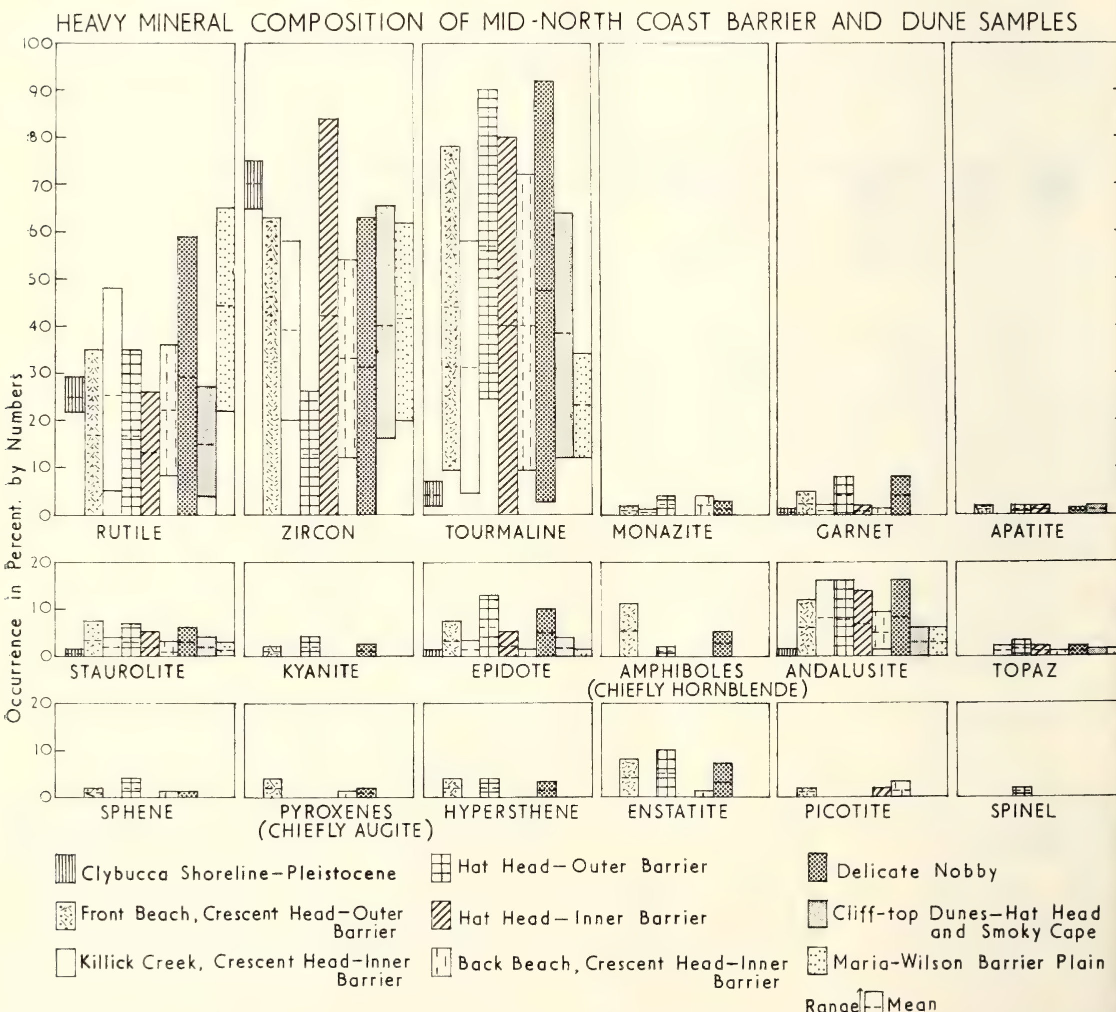

FIG. 7—Non-opaque heavy mineral composition of some barrier and dune samples collected on the Mid-North Coast.

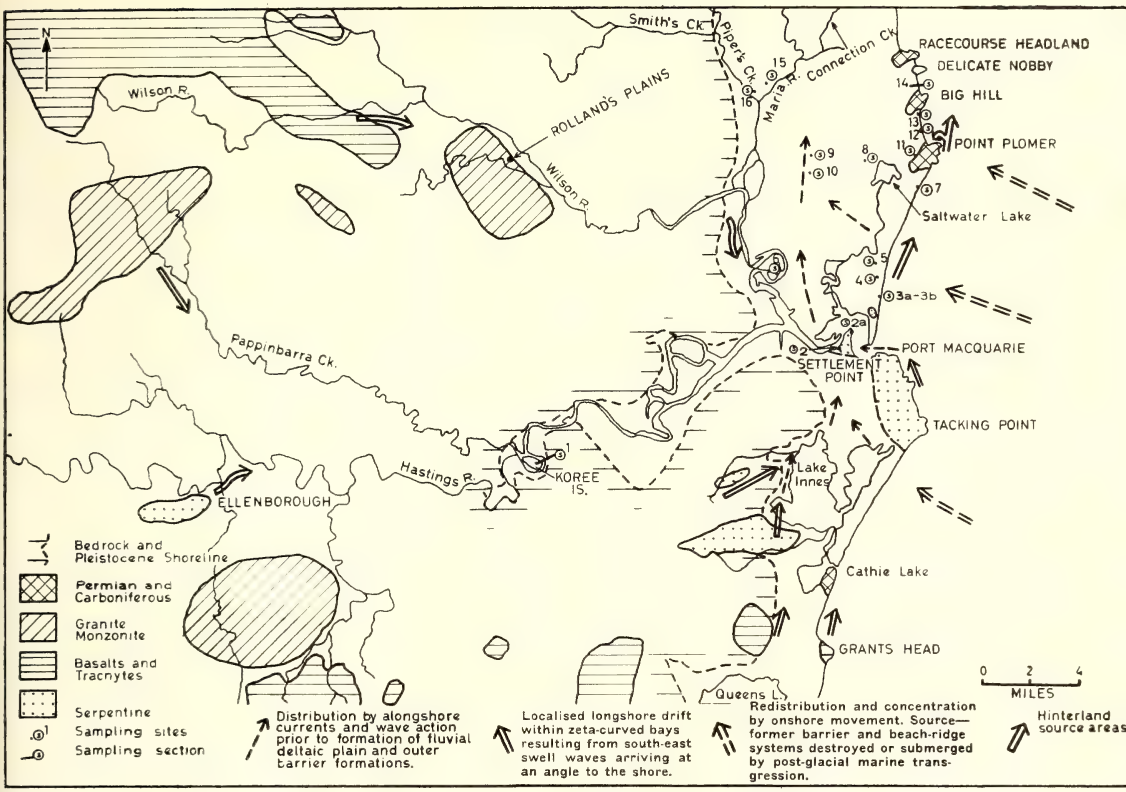

FIG. 8—Postulated sources of heavy minerals identified on the Mid-North Coast.

well rounded minerals collected from the other two study areas (Plates 1A–1C; 1G–1I). Both Twofold Bay and Broken Bay are fairly well sheltered from wave action compared with the arcuate bays on the exposed Mid-North Coast, but even so, the Broken Bay minerals, except those of the Patonga barrier, are well rounded compared with the Boyd Town samples. The slightly lower values of the Patonga samples indicate that the material carried into Brisk Bay by Patonga Creek has travelled a relatively short distance from its source. In general, the roundness values reflect the polygenetic history of most of the Broken Bay minerals.

(*b*) *Broken Bay Samples:*

The analyses of Broken Bay samples provide some interesting information. Although hypersthene occurs in relatively few samples, its presence warrants some comment. Hypersthene is one of the least persistent minerals in the geologic column, and it is generally found in sediments derived from nearby hypersthene-bearing rocks, such as gabbros, norites, dolerites, basalts, andesites, and volcanic tuffs. According to David (ed. W. R. Browne, *op. cit.*), the Chocolate Shales of the Middle Narrabeen Series are usually regarded as redistributed fine basic tuff with a large admixture of purely clastic material. On the other hand, he states that the Hawkesbury Series is thought to be entirely free from volcanic material, though the Upper Wianamatta Stage is characterized by a large proportion of calcareous sandstone which is tuffaceous. Therefore, it seems that the hypersthene is being derived from such rocks in the Broken Bay hinterland since it has been identified in nearshore sediments collected by the writer from Brisk Bay. The mineral has been traced in four Holocene samples, but it is absent from the Umina-Woy Woy Pleistocene (?) barrier sands. The fact that hypersthene is not very resistant to abrasion is also supported by the results of Culey's (1933) mineralogical study of the Narrabeen Series; only one hypersthene grain was identified in samples collected at the Entrance, Tuggerah.

The contention that volcanic material is being weathered in the vicinity of Broken Bay is also supported by the appearance of titan-augite in a few samples. The presence of picotite is not considered particularly significant because the

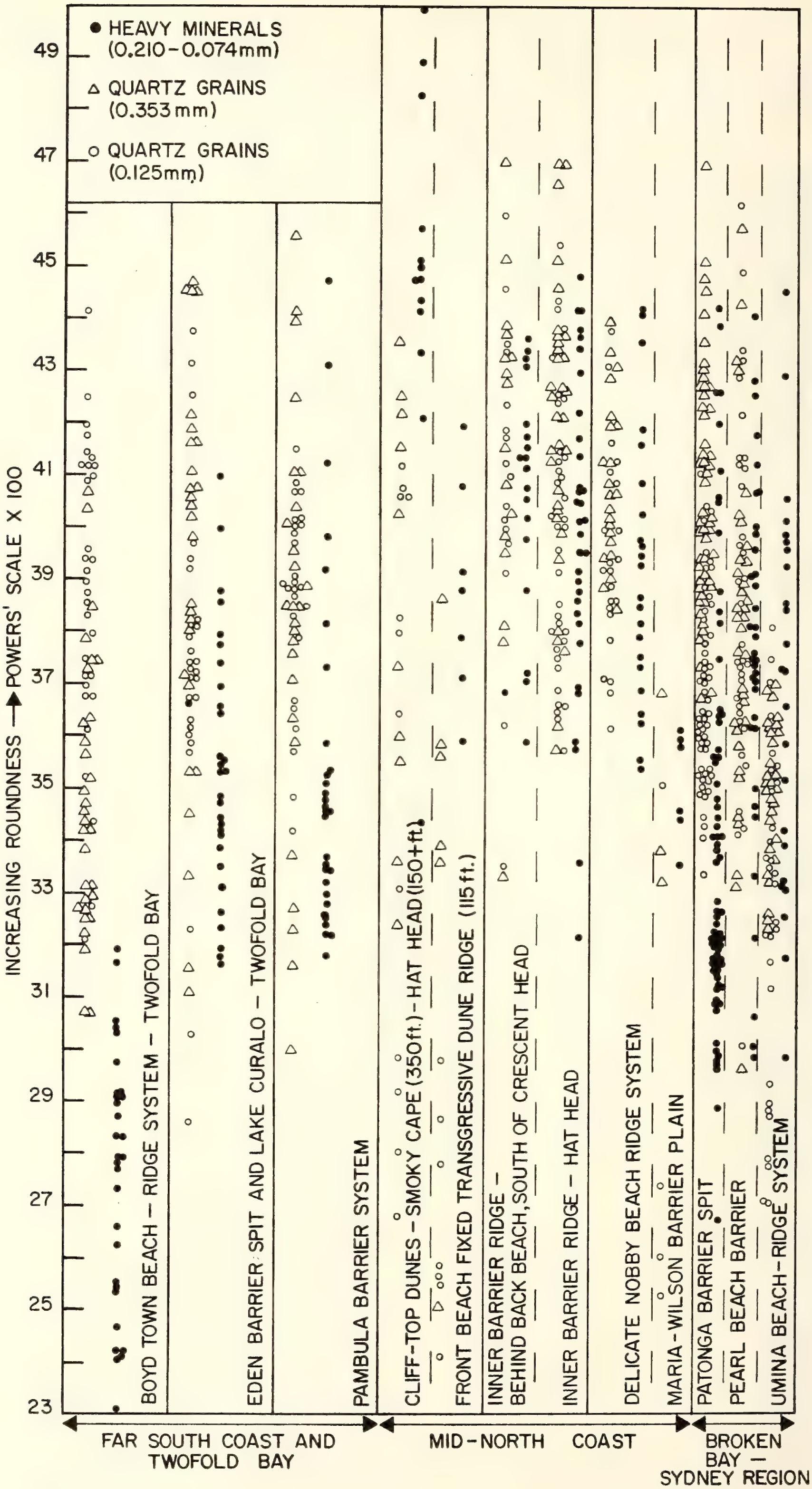

Fig. 9—Roundness values of quartz and heavy minerals, plotted on the Powers' scale.

mineral occurs in minor proportions in the various horizons of the Narrabeen Series. Staurolite is seldom found in Broken Bay samples, but garnet and andalusite are more common minerals. Unfortunately, the heavy mineral assemblage of the Pearl Beach and Patonga barriers does not provide clues on the movement of material around headlands, because it is identical with that of the Umina-Woy-Woy barrier system.

(*c*) *Mid-North Coast Samples :*

Distinctive constituents of the Mid-North Coast Pleistocene and Holocene barrier and dune sands are andalusite, staurolite, garnet, kyanite, zoisite and epidote. This heavy mineral suite suggests a medium-grade metamorphic source of which, however, there is no trace in the areas drained by the Mid-North Coast rivers. Although sillimanite-bearing metamorphic rocks occur in the Wongwibinda Complex (Binns, 1965), north-east of Armidale, sillimanite is absent from the coastal samples either because of its low chemical and mechanical stability, or because the tributaries of the Macleay River do not drain the Wongwibinda area. It is possible, therefore, firstly, that the observed metamorphic minerals were derived from a source which has been entirely removed by erosion. Secondly, they were eroded from cliffs and headlands, or delivered to the coast by rivers, outside the region thus necessitating the longshore movement of material around headlands and over considerable distances. Thirdly, the minerals were deposited as rivers extended their courses across the emerged continental shelf during Pleistocene low stands of sea level and were reworked and transported shoreward by wave action during subsequent marine transgressions. Fourthly, they were derived from a metamorphic source that was submerged during the post-glacial and earlier Pleistocene marine transgressions.

A similar heavy mineral assemblage to that of the coastal sands has been identified in bed load samples collected from the Hastings River, and Stockyard Creek which predominantly drains a serpentine rock area in the Macleay River catchment (Lindsay, 1963). However, the metamorphic minerals in the samples from Settlement Point on the Hastings River (Numbers 2–2a, in Figures 3 and 8) may have moved upstream from offshore because the river is tidal at this locality.

The presence of picotite in the river sands is also of some interest since as a detrital mineral it is of very restricted occurrence. Therefore it appears that the picotite identified in the Stockyard Creek samples, and those collected near Sherwood Bridge upstream from the tidal limit of the Macleay River at Aldavilla (Number 306, Figure 3), has been derived locally from the serpentine rock area. The occurrence of this mineral in the modern beach and Holocene barrier sands north of the Macleay River outlet in Trial Bay suggests that the heavy minerals reaching the coast are not transported southwards around headlands by longshore currents, but nearshore experiments, using radioactive or fluorescent tracer sand, are needed to verify this opinion. A northerly movement of material alongshore is also indicated by the occurrence of picotite in the Pleistocene and Holocene coastal sands north of Port Macquarie because the only other major serpentine rock areas on the Mid-North Coast are located south of the Hastings River (Figure 8).

Enstatite, hypersthene, kyanite, spinel, hornblende and augite are generally absent from the Inner Barrier and Pleistocene dune sands. Therefore, aeolian action seems the most plausible explanation to account for the unique presence of enstatite and augite in the Back Beach Pleistocene sands between Race Course Headland and Crescent Head. These minerals have been identified in samples collected within three feet of the surface of the barrier. The reason why they should be transported from the adjacent Outer Barrier on this section of the Mid-North Coast and not elsewhere is still a problem that has to be resolved.

The persistence of certain heavy minerals in the Mid-North Coast sediments appears to be determined by either their chemical or mechanical stability. For example, staurolite has an extremely low stability to weathering index compared with zircon and tourmaline and therefore its occurrence is attributed to its resistance to abrasion. Despite its relatively high position in the Order of Persistence Table (5B), biotite however appears to be an unstable mineral since it is absent from all the samples that have been analyzed, including the Holocene barrier sands and fluviatile sediments.

According to Baker (1962) though, differences in stability of any particular mineral undoubtedly exist in different areas according to variations in climate, topography and vegetation. Allen (1948), on the other hand, stated that the resistance of minerals to weathering depends upon the particular variety of the mineral in question. Dryden and Dryden (1946) in their study of the comparative rates of weathering of common heavy minerals *in situ* discovered that

garnet is the least resistant to chemical alteration, even though most other workers list this mineral as highly stable.

It is generally accepted that the mechanical stability of minerals like tourmaline, rutile and zircon, for example, is controlled largely by their physical properties. Figure 9 shows that the heavy accumulates in the Mid-North Coast barrier and dune sands are composed of fairly well rounded minerals, and there is little difference between the values of Pleistocene and Holocene samples. This evidence partly supports the view put forward here that the minerals have been derived from ancient sediments and they have inherited their properties. Some minerals of course, can be derived locally and abraded in the surf zone before being redeposited as beach concentrates, but this seems unlikely on the Mid-North Coast because the mineralogical composition of the coastal sands differs from that of the adjacent bedrock headlands. Even so, the evidence does not entirely exclude the possibility that some minerals may have been derived from a source now submerged.

Contrary to the statements in some publications (Gardner, *op. cit.*; Beasley, *op. cit.*), the writer's analyses show that heavy minerals can be transported beyond the limit of high water mark. Although wave action is the initial cause of concentrating stable heavy minerals, the complementary effects of wind action seem to have been under-estimated (Hails, 1964). The mineral composition of Pleistocene and Holocene dune and barrier (and also modern beach) sands is basically similar, and the average weight per cent of heavy minerals in dune samples is 2·16 compared with 1·78 in barrier sands. Furthermore, the weight per cent of heavy minerals in the cliff-top dunes does not vary appreciably, irrespective of height above mean sea level and distance from immediate source areas. Specific gravity values of the different minerals in the dunes range from 2·98 to 5·18 and their hardness values (Mohs scale) range from 5 to 8 (Table 5A).

There appear to be two main reasons to account for the differences in the concentration of heavy minerals (by weight) in the Pleistocene and Holocene sands (Table 6). Firstly, there may have been low sediment yields from the river catchments in the past because of reduced erosion and slow weathering, or there were few heavy minerals offshore to be reworked and redeposited by wave action as the Pleistocene barriers were established. Also, nearshore processes may have controlled deposition only in certain areas. Secondly, ephemeral barriers existing off the present coast during periods of lower sea level, may have been partly eroded or destroyed before complete submergence during the late Holocene transgression. This process could have provided large supplies of sand for the construction of the Holocene Outer Barriers. However, temporary shorelines may not have existed immediately before the formation of the Inner Barrier. Undoubtedly, slight fluctuations in sea level and variations in local wave and wind regimes have controlled the concentration of heavy minerals since the major barriers were established (Hails, *op. cit.*).

Based on the accumulated evidence reported here, the writer has shown in Figure 8, the possible areas and sources from which some of the identified minerals have been derived. The closed arrows indicate the directions in which the minerals were transported to an embayed coast before the formation of the barriers and the deltaic plains. Dominant south-easterly swell waves, that arrived at an angle to the shore, undoubtedly moved some material northwards alongshore, and heavy minerals could have been

TABLE 5A

Specific Gravity and Hardness Values of Heavy Minerals Identified in Cliff-top Dunes

(Hardness values on Mohs scale)

Mineral	Specific Gravity	Hardness
Andalusite	3·16–3·20	7·5
Epidote	3·25–3·50	6–7
Ilmenite	4·50–5·00	5–6
Leucoxene	3·50–4·50	—
Magnetite	5·17–5·18	5·5–6·5
Piedmontite ..	3·45–3·50	6·5
Rutile	4·18–4·25	6·0–6·5
Staurolite	3·65–3·77	7·0–7·5
Topaz	3·51–3·61	8·0
Tourmaline ..	2·98–3·20	7·0–7·5
Zircon	4·20–4·86	7·5

TABLE 5B

Order of Persistence of Heavy Minerals in the Geologic Column

(Least persistent minerals are listed first. Minerals marked * occur in cliff-top dunes.) Table based on that of Pettijohn (1941). Read down columns

Olivine	Topaz*	Apatite
Actinolite	Andalusite*	Biotite
Diopside	Hornblende	Garnet
Hypersthene	Epidote*	Monazite
Sillimanite	Kyanite	Tourmaline*
Augite	Staurolite*	Zircon*
Zoisite* (epidote group)	Magnetite*	Rutile
Sphene	Ilmenite*	Anatase

Table 6

Range and Average Percentage Concentration by Weight of Heavy Minerals in Pleistocene and Holocene Sediments

Area/Location	Environment	Age	Heavy Mineral Concentration	
			Range	Average Percentage
Twofold Bay :				
Eden	Barrier spit	Holocene	0·1– 1·2	0·25
Boyd Town	Barrier beach ridges	Holocene	0·4–14·0	2·70
Whale Beach ..	Barrier spit	Holocene	0·2– 8·0	4·06
South Coast :				
Pambula	Barrier spit	Holocene	0·2– 4·6	0·96
Broken Bay :				
Pearl Beach ..	Barrier beach	Holocene	0·1–44·0	8·37
Umina-Woy Woy ..	Barrier beach ridges	Holocene	0·1–14·6	3·45
		(?) Pleistocene	0·6–22·0	2·74
Patonga Beach ..	Barrier spit	Holocene		
	(ridges)		0·1– 7·0	0·28
	(swales)		0·1– 3·0	0·23
	(foredune)		0·2– 1·8	0·49
	(random bores)		0·1–56·0	6·81
	Grand total		0·1–56·0	1·45
Patonga Offshore ..	Neritic	Holocene	0·1– 2·0	0·44
Mid-North Coast :				
Delicate Nobby ..	Barrier ridges	Holocene on Pleistocene	0·2–13·0	2·05
Back Beach	Inner barrier	Pleistocene	0·4– 6·6	2·30
Killick Creek	Inner barrier	Pleistocene	0·2–15·0	4·13
Front Beach	Outer barrier	Holocene	0·1– 7·6	1·14
Hat Head	Outer barrier	Holocene	0·2– 2·0	0·58
Hat Head	Inner barrier	Pleistocene	0·1– 5·2	0·76
Hat Head	Cliff-top dunes	Pleistocene	0·4– 2·4	1·50
Smoky Cape	Cliff-top dunes	Pleistocene	0·8– 7·8	3·56
Front Beach	Transgressive dunes	Pleistocene	0·2– 1·4	0·91
Clybucca shoreline ..	Beach ridges	Pleistocene	18–50·6	32·62

concentrated locally as waves were refracted around promontories, as indicated by the dashed arrows. However, the longshore movement of material was incidental to that moved onshore (open dashed arrows). The open arrows in Figure 8 show the most probable direction of longshore drift in the modern arcuate bays.

Summary and Conclusions

Locally derived titan-augite and diopsidic augite are the distinctive constituents of South Coast sediments. The occurrence of hypersthene in the Broken Bay barrier samples seems to indicate a volcanic rock source in the Patonga Creek catchment.

All the Mid-North Coast minerals are polygenetic because they have been derived from various sources, and have survived several phases of rock formation and weathering.

Andalusite, staurolite, garnet, kyanite and epidote are the most distinctive constituents of the Mid-North Coast sands and suggest a medium-grade metamorphic source of which there is no trace in the area drained by the Mid-North Coast rivers. It is therefore possible, firstly, that the minerals were derived from a source which has been entirely removed by erosion ; secondly, from other regions by being transported alongshore ; and thirdly, from offshore.

The picotite in the beach and barrier sands north of the Hastings and Macleay Rivers has been derived from the sepentine rocks in the Hastings River basin and from the small outcrops near Stockyard Creek.

The percentage occurrence (by number) of the common detrital minerals in the Pleistocene and Holocene barrier and dune sands does not vary appreciably. The most common detrital minerals on the Mid-North Coast and in Broken Bay are rutile, zircon, tourmaline and the opaques. Hornblende, the pyroxenes, and members of the epidote group are the most common

minerals on the South Coast. Most minerals in the dunes on the Mid-North Coast were probably derived from neighbouring barrier and beach sands. The mineralogical composition of the cliff-top dunes reflects the strength and transporting power of wind.

The sub-angular minerals derived from the various catchments on the South Coast are not rounded appreciably by abrasion in the surf zone before being deposited as beach concentrates in the small embayments. Twofold Bay sediments are comparatively angular compared with those of the other two study areas. There is little difference between the roundness values of the Pleistocene and Holocene heavy minerals on the Mid-North Coast mainly because the minerals are polygenetic.

A possible sequence of events which led to the concentration of heavy minerals in the Holocene beach and dune deposits was the :

(i) formation and establishment of barriers a short distance from the coast ;

(ii) complete or partial destruction of those barriers during a rise in sea level ;

(iii) redeposition of heavy minerals along a newly established shoreline ;

(iv) modification of that shoreline by aeolian action and storm waves.

Finally, should coastal erosion cause foredune or beach ridge destruction, heavy minerals may become concentrated as the lighter quartz grains are removed. If erosion is followed immediately by a period of shoreline progradation, the minerals will be preserved as a concentrated deposit.

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Explanation of Plates

PLATES 1A-1C Heavy minerals in

A. Hat Head cliff-top dune samples. (×58.)

B. Smoky Cape cliff-top dune samples. (×36.)

C. Front Beach transgressive dune samples. (×36.)

1. Piedmontite.	5. Leucoxene.
2. Zircon.	6. Magnetite.
3. Rutile.	7. Andalusite
4. Tourmaline.	8. Ilmenite.

PLATES 1D-1'I' Heavy minerals in

D. Boyd Town beach ridge system. (×36.)
*A—Amphibole. T/Aug—Titan-augite.
E—Epidote. P—Pyroxene.
H—Hornblende.

E. Whale Beach barrier. (×36.)
M—Magnetite.

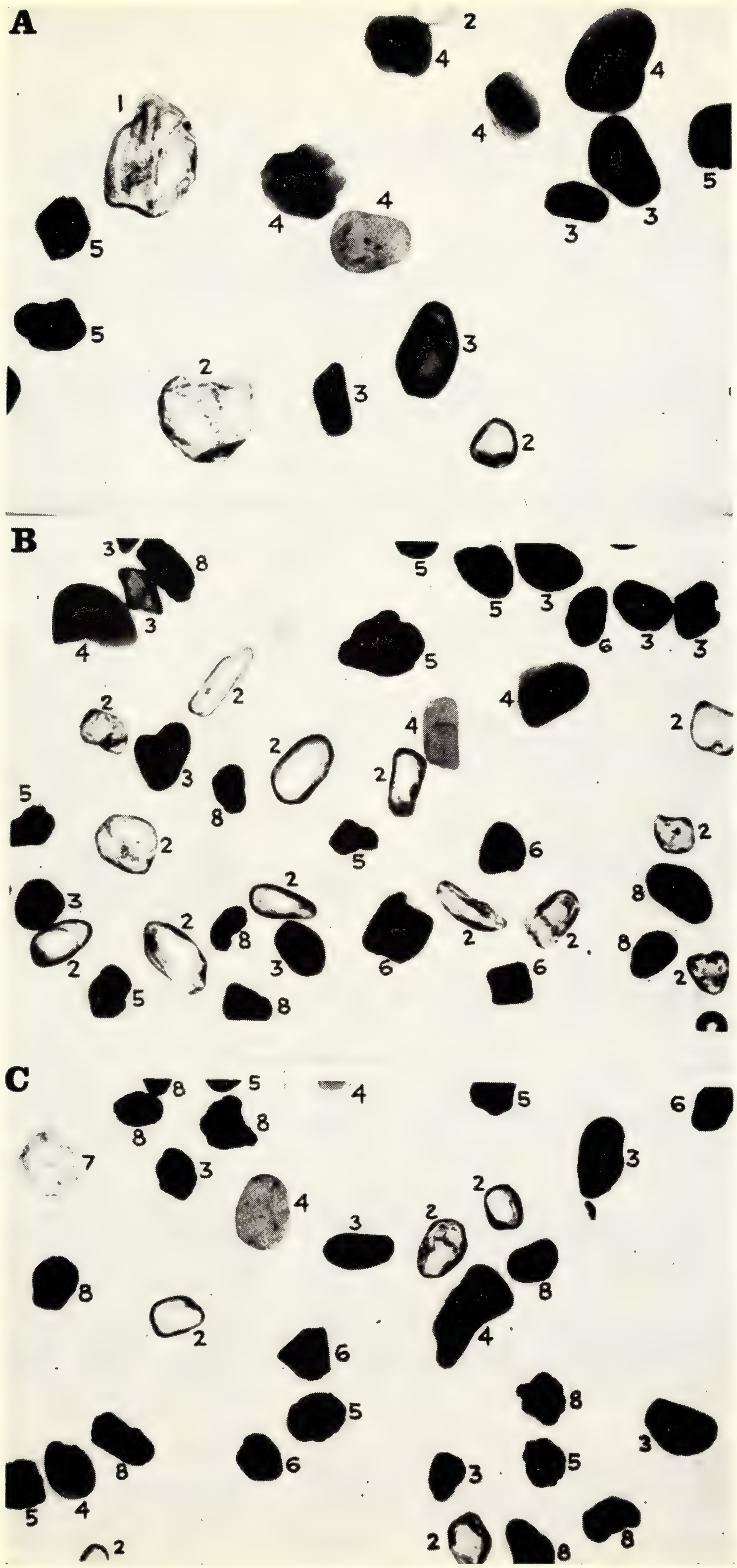
F. Pambula barrier spit. (×58.)

G. Number 3*a*–3*b*, Fig. 3, north of Port Macquarie.
An—Andalusite. T—Tourmaline.

H. Patonga barrier spit, Broken Bay. (×36.)
R—Rutile. Z—Zircon.

'I'. Macleay River—Sherwood Bridge. (×36.)
T—Topaz.

* Same symbols as for D'I' unless shown otherwise.


A
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D
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Stratigraphy and Structure of the Palaeozoic Sediments of the Lower Macleay Region, North-eastern New South Wales

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ABSTRACT—The Palaeozoic sedimentary rocks of the lower Macleay region have been divided into six stratigraphic units which are, in ascending order ; the Boonanghi Beds, the Majors Creek Formation, the Kullatine Formation, the Yessabah Limestone, the Warbro Formation and the Parrabel Beds.

The lowest exposed Carboniferous sedimentary rocks are turbidites ; these pass upwards into poorly-washed sandstones and mudstones, which are in turn overlain by a well-washed shallow-water sequence of sandstones, conglomerates, and mudstones. The oldest Permian rocks exposed are bioclastic limestones that pass upwards into interbedded mudstones and sandstones, some of which are laminated.

There are two distinct sets of faults, one intersecting and displacing the other, and a set of major folds carries some incongruent minor folds.

Introduction

This paper presents data on the stratigraphy and structure of Palaeozoic sedimentary rocks exposed in the lower Macleay region to the west of Kempsey, in northeastern New South Wales. The region is approximately 34 miles (54 km.) long and 21 miles (34 km.) wide and has an area of approximately 700 square miles (1800 km^2). It includes part of the coastal lowlands and part of the escarpment leading up to the New England Tablelands. The elevations range from 500 to 3,000 feet (150 to 900 m.).

Previous Investigations

Early maps show Devonian and Silurian rocks in the Kempsey district. De Koninck (1898) described fragmentary fossils that apparently came from the mudstones associated with the Yessabah Limestone, and considered them to be probably of Devonian age. Dun (1898) listed a collection of fossils from six miles (9·7 km.) west of Kempsey, probably from the vicinity of Gowings Mountain, and assessed their age as Permo-Carboniferous.

Woolnough (1911) gave the first account of the areal geology of the Macleay district, produced a sketch map, and described briefly the Yessabah Limestone at Moparrabah and Mount Sebastopol. He concluded that the limestone was Permo-Carboniferous in age and suggested a correlation with limestone at Pokolbin in the Hunter Valley. Woolnough correlated rocks underlying the limestone with the Lochinvar beds of the Hunter Valley.

A later reconnaissance sketch map by Carne and Jones (1919) showed all the known localities of the Yessabah Limestone. They also gave a brief description and some chemical analyses of the limestone. The geological map of the Commonwealth of Australia published in 1932 showed the district as consisting of " Lower Marine " rocks with Carboniferous to the south. The " Nambucca Phyllites " were shown to the north of the " Kempsey Area Fault ", and assigned to the Upper Silurian.

A more detailed regional map was published by Voisey (1934), who defined the Parrabel Anticline, made the first stratigraphic divisions of the sequence, and correlated the units with similar units elsewhere in eastern New South Wales and Queensland. Voisey (1936) described the results of detailed mapping of the structural complex in the vicinity of Yessabah, and he mentioned the district later in two papers on the Manning River region (Voisey, 1938, 1939*a*). In 1945 he correlated Carboniferous sequences throughout New South Wales and included some discussion of the lower Macleay region ; and in 1950 and 1958 he discussed the stratigraphic divisions of the sequence, and suggested correlations.

Campbell (1962) provided the first detailed age correlation for part of the Carboniferous sequence by describing two faunas from the Kullatine Formation.

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Stratigraphy

Most of the sedimentary rocks exposed in the lower Macleay region range in age from Lower Carboniferous to Lower Permian. Locally the hill tops are capped by river gravels of probable Pleistocene age.

The Palaeozoic sedimentary rocks of the lower Macleay region are at least 27,000 feet (8,200 m.) thick (Fig. 1). The Carboniferous sedimentary rocks range from turbidites at the base of the sequence to near-shore traction-current deposits at the top. The Permian sedimentary rocks are mainly interbedded sandstones and mudstones and have at their base a comparatively thin but very distinct crinoidal limestone.

Retaining Voisey's (1934, 1936, 1950, 1959) original nomenclature where possible, the author has divided the Permian and Carboniferous succession into six lithostratigraphic units (Fig. 2). In ascending order these are: the Boonanghi Beds, the Major Creek Formation, the Kullatine Formation, the Yessabah Limestone, the Warbo Formation and the Parrabel Beds. Other sedimentary rocks are discussed under " Undifferentiated Palaeozoic Sediments " and " High Level Gravels ".

Boonanghi Beds

The Boonanghi Beds were defined by Voisey (1934). The name is derived from the parish of Boonanghi. The unit comprises turbidites consisting mainly of regularly-graded lithic sandstone interbedded with laminated mudstone. Exposures of these sediments described by Voisey (1936, p. 186) along Dungay Creek are 1695 feet (519 m.) thick and are here defined as the type.

Lithology.—The unit consists mainly of interbedded sandstone and mudstone in a typical turbidite sequence, and contains infrequent beds of conglomerate with a discontinuous framework. Sandstone is more abundant toward the top of the unit, whereas laminated mudstone is the dominant rock type lower in the sequence. The sandstone is highly indurated, dark blue to blue green, relatively coarse-grained and poorly-sorted, and the grains are highly angular. Beds range from 1 inch to 20 feet (2·5 cm. to 6 m.) thick. Individual beds are graded and some contain angular chips of the underlying mudstone. The lower contacts of the beds are sharp and scour channels are common. Many beds have gradational upper contacts, whereas others have sharp upper contacts.

Mudstone forms approximately 87 percent of the lower part of the unit but only 10 percent of the upper part. Most of it is laminated, with alternating dark and light laminae between 0·25 and 4 inches (0·63 and 10 cm.) thick. The laminae are graded, cross-bedded, or structureless. The graded laminae are less than 0·05 inch (1·3 mm.) thick and are highly carbonaceous. The cross-bedded laminae are light-coloured and range from 0·2 to 0·5 inch (5 to 13 mm.) thick. They are generally weakly cross-bedded with the cross-beds lying at a low angle to the bedding plane. The structureless beds are light-coloured and much thicker than other beds (as much as 4 inches (10 cm.) thick). Worm trails occur in large numbers on the bedding planes and some are as much as 2 feet (60 cm.) long. Worm borings are present in some beds but are not as common as the trails. Soft-sediment distortion of bedding occurs in the mudstone at numerous localities and ranges in intensity from slight crenulations to complex overfolds and pull-apart structures.

Conglomerate with a discontinuous framework occurs at irregular intervals throughout the Boonanghi Beds but is more abundant in the basal portions. The beds are massive and range in thickness from 2 to 90 feet (0·5 to 27 m.); individual beds persist for as much as 5 miles (8 km.). At some localities a single unit consists of 3 or 4 individual beds of conglomerate. The upper and lower contacts are sharp and the base of many beds is a slight unconformity. The conglomerate consists of 5 to 30 per cent rounded phenoclasts as much as 8 feet (2·4 m.) in diameter and of a wide variety of lithologies. The phenoclasts are set in a fine-grained matrix of soft black mudstone or labile sandstone. The conglomerate at most localities contains slabs of laminated mudstone or armoured mudstone balls. The mudstone slabs reach 15 feet (4·6 m.) in length in some beds and are highly contorted.

Thickness.—Detailed measurements along Dungay Creek show the beds to be at least 5200 feet (1590 m.) thick.

Relation to Older Formations.—The base of the beds is not exposed in the area studied. The fact that the beds are subhorizontal and occur in the crest of an anticline suggests that the base of the beds probably is not exposed in adjacent areas.

Fauna and Age.—Voisey (1934, 1936) recorded the occurrence of *Loxonema* sp., *Rhipidomella* sp., and fragmentary fenestrate bryozoa, gastropods, and lamellibranchs. On the basis of

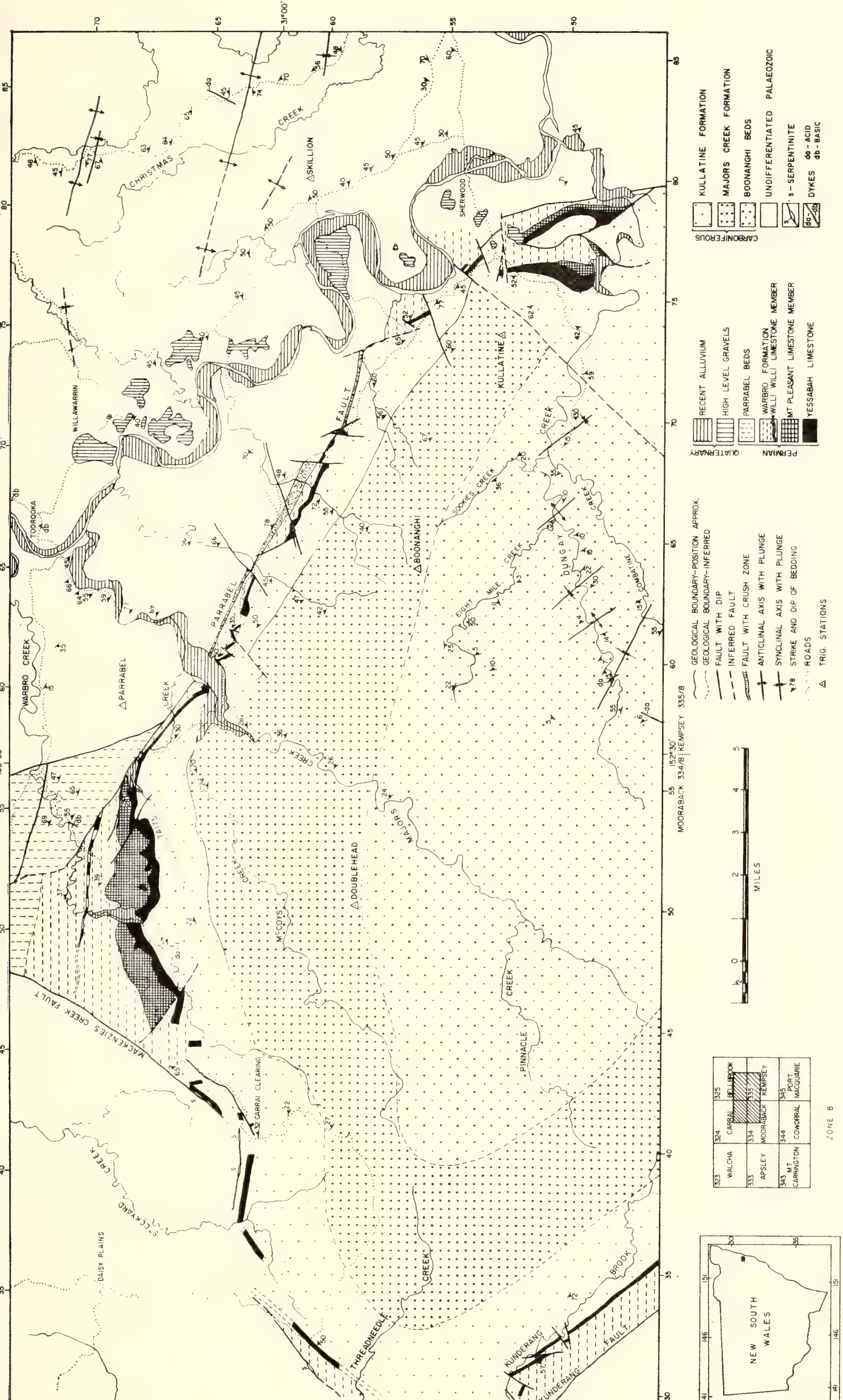

FIG. 1

Geological map of the Macleay district.

these fossils he correlated the Boonanghi Beds with " the Burindi Series of the Hunter Valley ". The fossil material was re-examined by the writer and it was found, as indicated by Voisey, that the fossils were too fragmentary to allow accurate determination of species.

Majors Creek Formation

The Majors Creek Formation is here defined as those sediments composed dominantly of massive labile sandstone and cherty mudstone that conformably overlie the Boonanghi Beds. The type section is defined as the section exposed along Majors Creek from 31° 01·5′ S, 152° 28·6′ E (Mooraback Military Map Sheet 334/8) to 30° 58·2′ S, 152° 31·7′ E (Bellbrook Military Map Sheet 325/8), which includes over 7,000 feet (2,100 m.) of sediments.

It appears that Voisey (1936, p. 187) included this formation in his Kullatine Series for he states " the lower beds of the Kullatine Series consists of sandstones, tuffs, sandy tuffs and breccias showing a great deal of variation in texture and composition, but possessing a general dark or light grey colour " and that they " must represent several thousands of feet of material ". The tuffs and sandstones referred to by Voisey appear to be the labile sandstone here included in the Majors Creek Formation.

Distribution.—The Majors Creek Formation is exposed in a broad belt following the form of the Parrabel Anticline. The belt is generally continuous and is only slightly disrupted by minor faults.

Lithology.—The formation is a traction current deposit of lithic sandstone and cherty mudstone.

The mudstone is black or dark blue, cherty, and has a rough conchoidal fracture. Most beds are massive and vary in thickness from 2 inches (5 cm.) to 3 feet (0·9 m.). A few beds are laminated ; some contain a little carbonaceous material.

The sandstone is blue or blue-green, fine-grained, and bedded in units from 2 to 12 feet (0·6 to 3·7 m.) thick, with an average thickness of about 4 feet (1·2 m.). The contacts of individual beds are sharp where the sandstone is inter-bedded with mudstone, but are confused by jointing where several sandstone units are bedded together. Some of the units are cross-bedded ; these units average 6 inches to 1 foot (15 to 30 cm.) thick.

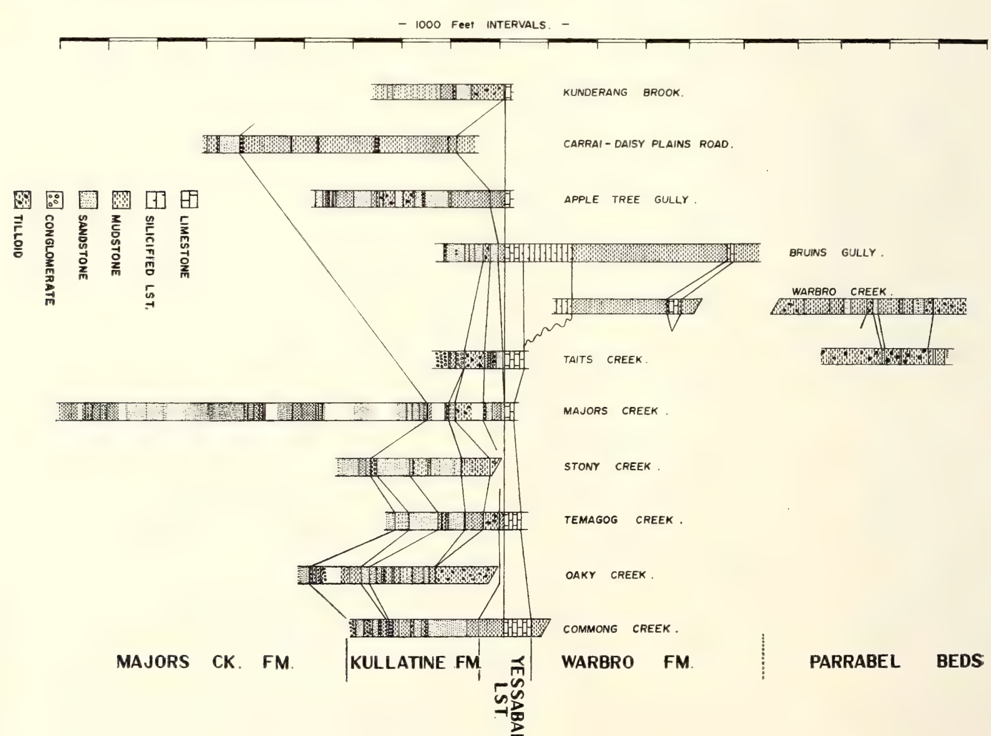

Fig. 2

Stratigraphic sections of the sedimentary rocks of the Macleay district.

Thickness.—In the type section the formation is 7,000 feet (2,000 m.) thick, but to the south it may be considerably thinner, as discussed below.

Relationship to Older Formations.—The contact between the Majors Creek Formation and the Boonanghi Beds appears conformable. The change in lithology resulted from a change from turbidity current transport to traction current transport. In the relatively inaccessible portion of the area to the south, the boundary between the two formations may transgress time planes and the Majors Creek Formation may disappear almost completely in the vicinity of Kunderang Brook. This change was apparently the result of a deepening of the basin to the south so that there the action of turbidity currents persisted to a much later time.

Fauna and Age.—Two fossil horizons have been found in the Majors Creek Formation. The lower horizon contains a branchiopod-bryozoa fauna, characterized by *Levipustula levis* Maxwell, which is similar to a fauna described by Campbell (1962) from the overlying Kullatine Formation. Species identified include: *Levipustula levis* Maxwell, *Spinuliplica spinulosa* Campbell, *Neospirifer pristinus* Maxwell, *Composita magnicarina* Campbell, *Fistulamina frondescens* Crockford, *Fenestella* spp., *Schizodus* sp. and *Peruvispira* sp. The presence of this horizon containing the *Levipustula* fauna 3,000 feet (915 m.) below the fauna described by Campbell from the Kullatine Formation poses several problems. Campbell compared his Kullatine fauna with similar faunas in other areas and concluded that it was Westphalian in age. However, lying stratigraphically between the two occurrences of the *Levipustula* fauna is another fauna containing the single species *Cravenoceras kullatinense* Campbell, which Campbell (1962) concluded to be Namurian in age. A detailed search revealed no structural complications and it can only be concluded that either one of the ages determined is incorrect or that the *Levipustula* fauna has a much greater age range than has been believed.

The second fauna contained in the Majors Creek Formation occurs close to the top of the unit and contains two small unidentified brachiopods and a small fenestrate bryozoan.

The formation is undoubtedly Middle to Upper Carboniferous in age, but is would be unwise to suggest any direct correlations with other formations until the faunal complications are resolved.

The Kullatine Formation

The name Kullatine Series was used by Voisey (1934) to include a sequence of coarse-grained rocks of freshwater origin with an Upper Carboniferous age. The name is derived from the parish of Kullatine where the rocks were first described by Voisey (1934). The Kullatine Formation is here redefined as the mudstone, sandstone, conglomerate, and diamictite conformably overlying the Majors Creek Formation and underlying the Yessabah Limestone. The section exposed along Temagog Creek from 31° 00·3′ S, 152° 36·5′ E to 30° 59·9′ S, 152° 36·5′ E (Kempsey Military Map Sheet 335/8) is here designated as the type section. The type section is 2,116 feet (645 m.) thick.

The Kullatine Formation as redefined is synonymous with the Taits Creek Formation and part of the Kullatine Series of Voisey (1958, p. 177, p. 179). In earlier papers Voisey referred the Taits Creek Formation to the Macleay Series (Voisey, 1934, p. 338–339; 1936, p. 187–189) and the Taits Creek Stage of the Macleay Series (Voisey, 1950, p. 66). Voisey based the division between the Taits Creek and the Kullatine Series on lithology and on lithogenesis indicated by fossil content. The presence of *Rhacopteris* in the Kullatine Series led him to believe that the unit was deposited under terrestrial conditions, whereas the Taits Creek Formation contains a marine fauna which led him to associate it with the Yessabah Limestone. Voisey (1950, p. 65) indicates that he found difficulty in separating the two units. The present author found that it was not possible to maintain the division between the two units on a purely lithologic basis, and for this reason the units have been redefined and the Taits Creek Formation and most of the Kullatine Series are here included in one formation—the Kullatine Formation.

Distribution.—The Kullatine Formation forms a relatively continuous unit arching broadly from Yessabah on Dungay Creek to Willi Willi. From Willi Willi it continues in a southwesterly direction to Kunderang Brook where it bends sharply to follow the creek. Over this distance the continuity of the formation is disrupted only slightly by minor faults.

Lithology.—The Kullatine Formation is a traction current deposit containing interbedded units deposited by subaqueous mass movement. Measurements of ten detailed sections of the formation show that sandstone and conglomerate make up the largest proportion of the sediments

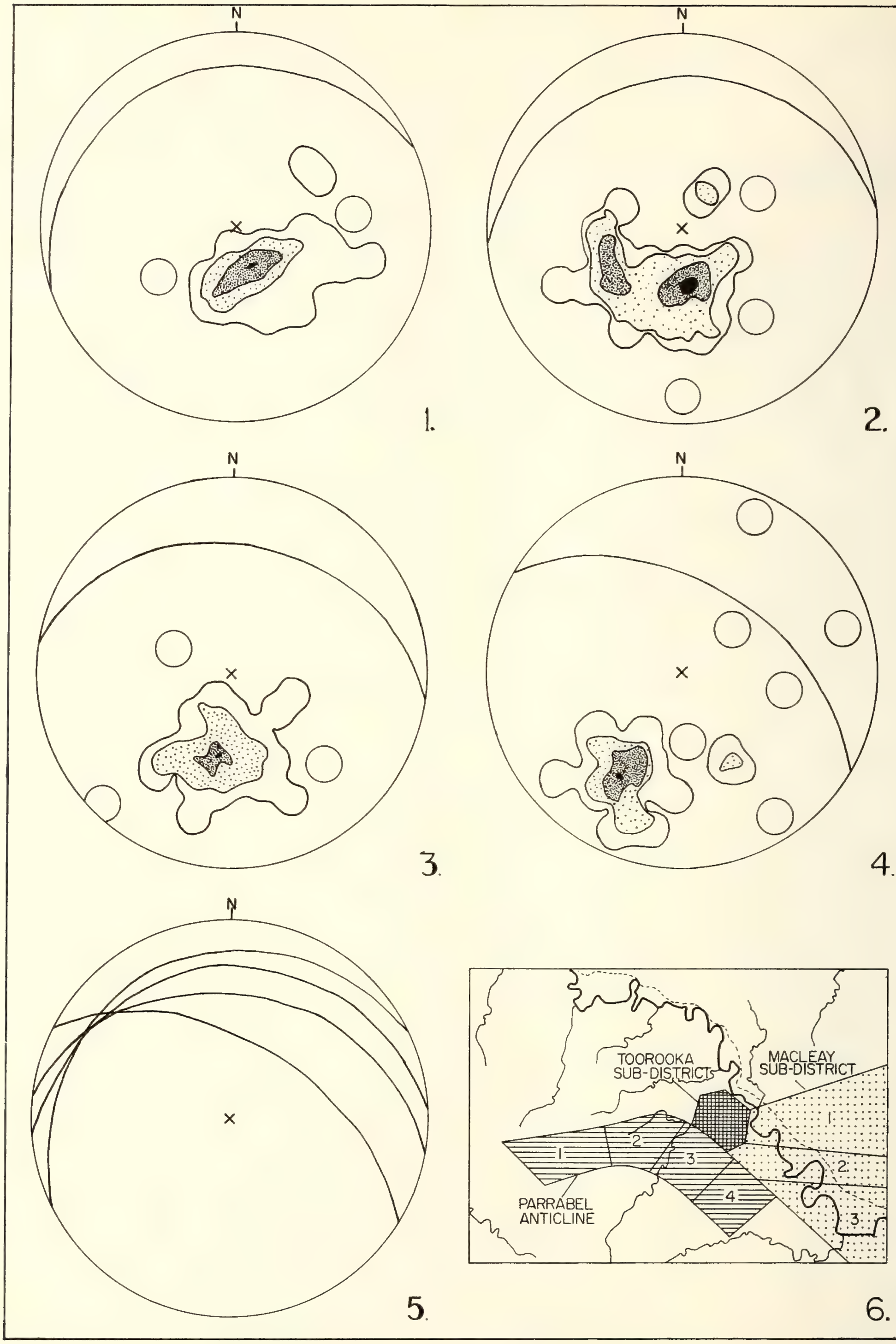

Fig. 3

S-pole diagrams of bedding plane attitudes for the Parrabel Anticline.

(*a*) Area (1) 52 readings, contours 0%, 10%, 20% and 30% per 1% area.
(*b*) Area (2) 34 readings, contours 0%, 5%, 10%, 20% and 25% per 1% area.
(*c*) Area (3) 42 readings, contours 0%, 10%, 20% and 25% per 1% area.
(*d*) Area (4) 34 readings, contours 0%, 10%, 15% and 20% per 1% area.
(*e*) Synoptic diagram showing intersection of mean bedding plane attitudes for all four areas.
(*f*) Map showing sub-districts and areas discussed in the structure of the lower Macleay region.

in the northern part of the area, whereas mudstone and finer sediments are dominant to the south. This, along with the occurrence of turbidites in the southern part of the area, suggests that the basin deepened considerably in a short distance to the south and that the sediment was being supplied from the north or north-west.

On the average, labile sandstone makes up 44 percent of the formation and is by far the most common rock type. Most of the sandstone is red or purple, but some beds near the base of the formation are blue-green. The sandstone occurs in well-bedded units 0·25 inch to 10 feet (6 mm. to 3 m.) thick. The contacts between the beds are sharp, although some beds exhibit loadcasts at their base. Sedimentary structures are not common, but graded beds are present in the turbidites to the south, and cross-bedding is present in some sandstone units in the northern sector. The sandstones at the base of the formation are coarse grained and well washed, but toward the top of the formation they are generally much finer and not as well washed.

Approximately 33 percent of the formation consists of grey or bright-purple mudstone, which is at most localities massively bedded in units up to 4 feet (1·2 m.) thick. The mudstones in the southern portion of the area are laminated and at some localities display large slump folds involving 10 to 20 feet (3 to 6 m.) of sediment. Apart from slump folds the only other common sedimentary features are sandstone dykes, which occur in the more massive beds of mudstone to the north.

About 6 percent of the formation consists of watersorted conglomerate, occurring as massive lenses over 300 feet (90 m.) thick and up to a mile (1·6 km.) in length, in the top 1,000 feet (300 m.) of the formation. Minor beds of conglomerate occur elsewhere in the formation but are generally less than 4 feet (1·2 m.) thick. The contacts between the conglomerate and the underlying sediments are sharp, although loadcasts occur locally where the underlying sediment is mudstone. The conglomerate is generally poorly sorted, ranging from medium-grained sand to boulders as much as 10 inches (25 cm.) in diameter. The coarse fraction is highly rounded.

The diamictites, which are considered to be mass-movement deposits (Lindsay, 1966) occur mainly in the upper 1,000 feet (300 m.) of the formation, although a few beds occur lower in the formation. These beds vary from 20 feet (6 m.) to over 200 feet (60 m.) in thickness. Laterally the beds are discontinuous and few extend for more than 200 yards (180 m.) along strike. They are very poorly sorted and range from silt to boulders 10 inches (25 cm.) in diameter. The coarse fragments are highly rounded. The fine fraction is fairly homogeneous in any one bed but varies in grain size from bed to bed. In some beds it is quite silty, in others sandy. Some of the beds contain large contorted masses of bedded sediment which were probably derived from the underlying beds while they were in a semi-consolidated state.

Thickness.—The formation ranges from 2,100 to 4,500 feet (640 to 1,370 m.) thick. The maximum thickness occurs in the vicinity of the Carrai clearing and the minimum at Majors Creek.

Relation to Older Formation.—The contact between the Kullatine Formation and the Majors Creek Formation in the northern part of the area has been mapped at the base of the lowest well-washed coarse-grained sandstone. Further south at Kunderang Brook the problem is not quite as simple, for the sediments are of deeper water origin and it may be difficult to separate the two formations. Changes in facies to be correlated with deepening of the basin to the south might prevent separation of the Carboniferous formations in this area. The contact between the Kullatine and Majors Creek formations is conformable at all localities examined. The change in lithology across the formational boundary in the northern portion of the area appears to be due to a shift in the strandline. The strandline shift resulted in the sandstones of the Kullatine Formation having a larger mean grain size and being well washed, in contrast to the fine-grained poorly-washed sandstones of the Majors Creek Formation.

Fauna and Age.—Campbell (1962) recorded three fossil horizons in the Kullatine Formation. A lower plant horizon is characterized by *Rhacopteris ovata* McCoy, a second is characterized by the small goniatite *Cravenoceras kullatinense* Campbell, and an upper horizon is characterized by the productid brachiopod *Levipustula levis* Maxwell.

Campbell considered the *Cravenoceras* fauna to be Namurian in age and the *Levipustula* fauna to be Westphalian. There are complications, for as mentioned earlier the *Levipustula* fauna occurs also in the Majors Creek Formation some 3,000 feet (1,020 m.) below the Kullatine occurrence.

Yessabah Limestone

The Yessabah Limestone was originally designated the Yessabah Stage by Voisey (1950) who subsequently changed the name of the unit to Yessabah Limestone (Voisey, 1958). The name comes from the village of Yessabah, near Kempsey. The formation consists of bioclastic limestone and calcareous mudstone conformably overlying the Kullatine Formation. As Voisey did not define a type section, it is defined here as the sediments exposed along Taits Creek from 30° 56·4′ S, 152° 29·9′ E to 30° 56·3′ S, 152° 30·0′ E (Carrai Military Map Sheet 324/8). The type section is 709 feet (216 m.) thick.

Distribution.—The formation occurs as a broad relatively continuous arch outlining the Parrabel Anticline. The continuity of the unit is disrupted slightly at numerous places by small normal faults. Blocks of the limestone are found at many localities in the crush zones of faults.

Lithology.—The formation comprises a basal calcareous mudstone overlain by bioclastic crinoidal limestone, the principal lithology, which is in turn overlain locally by silicified limestone of the Mount Pleasant Limestone Member.

The basal unit consists of soft bright-green calcareous mudstone that is locally highly fossiliferous. The unit is generally thin but in some places is 300 feet (102 m.) thick and forms as much as 30 percent of the formation. The mudstone is well-bedded and locally contains thin beds of crinoidal limestone. Where the beds are thin, crinkling or microfolding is commonly developed. The amount of deformation of fossils suggests that the mudstone suffered at least a 50 percent reduction in volume during compaction.

The bioclastic limestone occurs in massive beds about 10 feet (3 m.) thick. The limestone is pink or white at most localities and consists of well-sorted well-rounded bioclastic grains with an average maximum grain size of 4·9 mm., set in a microcrystalline matrix. A typical modal analysis is: crinoid fragment 43·3 percent, bryozoan fragments 25·9 percent, detrital quartz 0·3 percent, microcrystalline calcite 17·7 percent, sparry calcite 2·4 percent, rim cement 5·9 percent, and recrystallized calcite 4·5 percent (terminology after Stauffer, 1962, p. 360). Whereas the bioclastic fragments in most beds are dominantly crinoidal, the fragments in many beds are dominantly bryozoan. The limestone is 87 to 97 percent $CaCO_3$.

The Mount Pleasant Limestone Member is a silicified bioclastic limestone, in beds 3 to 6 feet (0·9 to 1·8 m.) thick, containing a few beds of calcareous mudstone and red chert. Unlike the main limestone unit, the silicified limestone consists mainly of interlocking fragments of the branching coral *Cladochonous* with subordinate amounts of crinoid, bryozoan, brachiopod and pelecypod fragments. The beds of calcareous mudstone are 2 to 6 inches (5 to 15 cm.) thick and at some localities contain well-preserved fossils. The beds of red chert are relatively uncommon and most occur near the top of the formation. The member varies in thickness from a feather edge to 1,000 feet (300 m.). The limestone grades laterally into cherty black laminated mudstone, which in turn grades into the Warbro Formation.

Thickness.—The formation varies in thickness from 20 feet (6 m.), where it crosses Stone Creek, to 1,500 feet (460 m.) at Willi Willi. The areas of greatest thickness, particularly at Willi Willi and Yessabah, are due to the presence of the Mount Pleasant Limestone Member. The main limestone unit changes thickness only gradually along strike, whereas the Mount Pleasant Limestone Member at Willi Willi increases in thickness from a feather edge to 1,000 feet (300 m.) in less than 2 miles (3·2 km.). The variation in thickness of the main crinoidal limestone appears to be due to variations in bottom topography at the time of deposition, with the greatest thickness of sediment accumulating in the hollows. The Mount Pleasant Member appears to be a series of reef-like bodies whose development depended on local environment conditions.

Relation to Older Formations.—The contact between the Yessabah Limestone and the Kullatine Formation is conformable. The base of the Yessabah Limestone is mapped at the base of the lowest calcareous sediment above the detrital sediments of the Kullatine Formation. The contact represents a distinct change in sedimentation from dominantly terriginous sediments in the Kullatine Formation to bioclastic sediments in the Yessabah Limestone. At most the calcareous mudstones contain only 10 percent of terriginous material.

Fauna and Age.—The Yessabah Limestone contains an abundant fauna of at least 33 species. Campbell (1962) concluded that the fauna was Sakmarian in age because it contains *Anidanthus springsurensis* (Booker), *Eurydesma cordatum* (Morris), and *Deltopecten mitchelli*

(Etheridge and Dun), all of which occur widely throughout eastern Australia in rocks considered to be Sakmarian.

The position of the Permian-Carboniferous boundary is not known but from the faunal evidence it must be close to the contact between the Kullatine Formation and the Yessabah Limestone.

Warbro Formation

The Warbro Formation was originally called the Warbro Stage by Voisey (1950) and later (Voisey, 1958) renamed the Warbro Formation. He derived the name either from the parish of Warbro or from Warbro Creek along which the beds are exposed. The formation consists of a sequence of interbedded lithic sandstones and mudstones with a thin crinoidal limestone which is here designated the Willi Willi Limestone Member. The formation conformably overlies the Yessabah Limestone. As a type section was not previously established for this formation, the section exposed along Warbro Creek from 30° 56·3′ S, 152° 26·4′ E to 30° 55·6′ S, 152° 26·5′ E (Carrai Military Map Sheet 324/8) is here designated the type. The type section is 3,380 feet (1,031 m.) thick.

Distribution.—The largest exposed area of the Warbro Formation is at Willi Willi where it occurs in a series of wedge-shaped blocks, bounded by the Parrabel and Mackenzies Creek faults and their associated splay faults. A smaller area, at Yessabah, is bounded by several small faults. Several minor exposures occur as narrow strips between the Yessabah Limestone and the Parrabel Fault.

Lithology.—The lithic sandstones and mudstones in the basal 500 feet (150 m.) of the formation are bedded in laminites I (Lombard, 1963). The bedding above the Willi Willi Limestone Member is more massive and the bedding planes less distinct. The beds of mudstone vary from 1 to 10 inches (2·5 to 25 cm.) in thickness near the base of the formation to over 8 feet (2·4 m.) in thickness above the limestone member. The fresh rock is black or grey and breaks readily to slivers. The mudstone is rarely exposed because it weathers readily to brown or yellow clayey soil. The lithic sandstone froms 20 to 25 percent of the formation and occurs in beds varying from a maximum thickness of 4 inches (10 cm.) in the laminites at the base of the formation to over 8 feet (2·4 m.) toward the top. The sandstone in the laminites has sharp contacts and individual beds are nearly constant in thickness along the strike. The sandstone in the lower part of the formation is pale grey; some higher in the formation is olive green.

The Willi Willi Limestone Member is a unit of massive bioclastic crinoidal limestone that varies from 50 to 200 feet (15 to 60 m.) in thickness and occurs approximately 3,000 feet (900 m.) above the base of the formation. Beds are outlined at some localities by stylolites, and bands of fossils every 2 to 3 inches (5 to 7·5 cm.). The limestone is dark grey or brown and locally contains angular fragments of green mudstone as much as 4 inches (10 cm.) in diameter. One sample of the limestone consists of about 55·3 percent crinoidal fragments, 3·3 percent bryozoan fragments, 1·8 percent brachiopod and pelecypod fragments, 0·8 percent terriginous material, 19·7 percent recrystallized calcite, 0·2 percent sparry calcite, and 18·9 percent microcrystalline calcite. Other samples are similar.

Thickness.—The formation is at least 3,500 feet (1,070 m.) thick; faults within the measured sections make knowledge of the total thickness uncertain.

Relation to Older Formations.—At most localities examined the Warbro Formation conformably overlies the Yessabah Limestone. However, at Yessabah and Willi Willi the lower portion of the Warbro Formation grades laterally into the Mount Pleasant Limestone Member, such that, at least in part, they are lateral equivalents.

Fauna and Age.—Identifiable fossils are rare in the Warbro Formation. The only genus identified is *Terrakea* (?) from the Willi Willi Limestone Member.

Parrabel Beds

The Parrabel Beds, as here defined, consist of a sequence of inter-bedded mudstones, lithic sandstones, and conglomerates, which appear to overlie the Warbro Formation. The top of the unit is faulted in all sections known. The name of the unit is derived from nearby Mount Parrabel. A typical section of these rocks is exposed along Warbro Creek from 30° 54·3′ S, 152° 29·8′ E to 30° 54·8′ S, 152° 29·1′ E (Carrai Military Map Sheet 324/8), where they are 1,583 feet (483 m.) thick. These rocks have not previously been described.

Distribution.—The Parrabel Beds are exposed in a series of fault blocks in the hills to the north and east of the Willi Willi area. The fault blocks are the product of the splay faults associated with the Mackenzies Creek and Parrabel faults.

Lithology.—Mudstone forms about 40 percent of the sequence. It is blue-green, hard, cherty or olive-green, soft, and calcareous. The hard cherty mudstones are at most localities strongly laminated and generally occur interbedded in thin units with sandstone beds of similar thickness. The softer olive-green mudstones are much more massive and at some localities are richly fossiliferous. The sandstones occur in beds from 1 inch to 5 feet (2·5 cm. to 1·5 m.) thick and form approximately 8 percent of the unit. The contacts of these beds are sharp and load casts occur on the base of some.

The conglomerate forms about 32 percent of the beds and occurs in massive units which range in thickness from 10 inches (25 cm.) to more than 200 feet (60 m.). The beds have sharp contacts and some individual units persist along strike for several miles. The conglomerate consists of approximately 90 percent matrix with 10 percent pebbles and cobbles forming a continuous framework. The pebbles and cobbles, which were derived mainly from sedimentary and plutonic rocks, average 1 to 2 inches (2·5 to 5 cm.) in diameter and some reach a maximum of 6 inches (15 cm.) in diameter. The matrix varies from black or green mudstone to blue-green lithic sandstone.

Thickness.—The upper and lower limits of the unit are not known with any certainty; the incomplete sections examined suggest a total thickness in excess of 4,000 feet (1,220 m.).

Relation to Older Formations.—At most localities the base of the unit is interrupted by faulting. To the north of Willi Willi, the Parrabel Beds and the Warbro Formation appear to be conformable.

Fauna and Age.—A fauna of branchiopods, pelecypods, and bryozoa occur at two horizons in the formation, but identification of species has not been made.

Undifferentiated Palaeozoic Rocks

Sediments northeast of the Parrabel Fault

Woolnough (1911) was the first to comment on these rocks when he made the following statement: "On the east, the Silurian rocks are bounded by a series of contorted and cleaved quartzites and slates which we may refer to as the Kempsey Slates". Woolnough made no suggestions as to the age of the rocks except that by inference he did not include them with the strongly deformed undifferentiated Palaeozoic rocks (his Silurian rocks) to the north. Voisey (1934, 1936) referred to the same rocks as the Kempsey Series about which he said (Voisey, 1934, p. 340) "the Kempsey Series appears to follow the trend of the Parrabel Anticline from Willawarrin to Kempsey but has not been satisfactorily separated from the soft marine beds at the top of the Macleay Series (Lower Permian)—a fact which indicates a Permian age for part at least". In 1950, Voisey reported a "marine Carboniferous shell Fauna" from a quarry beside the Kempsey-Telegraph Point road, and this coupled with the discovery of *Rhacopteris* beside the same road in rocks lithologically similar to the Kempsey Series led him to abandon his earlier ideas of a Permian age in favour of a Carboniferous age for the Kempsey Series.

Two distinct lithologies were recognized in the sediments to the northeast of the Parrabel Fault. The first lithologic type occurs in the area between the Parrabel Fault and the Macleay River. The sediments are well exposed along the lower reaches of Majors and Stony Creeks where at least 4,000 feet (1,220 m.) of section is exposed.

The unit consists of sandstone and mudstone interbedded in laminites, with occasional beds of polymictic conglomerate distributed at irregular intervals through the sequence. The mudstones occur in beds 2 to 4 inches (5 to 10 cm.) thick that are made of laminae 0·125 to 0·25 inch (3 to 6 mm.) thick. The individual laminae vary considerably in thickness and in some beds they lens out in an inch or less. Worm trails and worm borings occur in small numbers in some beds. Sandstone forms approximately 30 percent of the unit and occurs in beds 1 inch to 1 foot (2·5 to 30 cm.) thick. The upper contacts of most of the sandstone beds are gradational, and angular fragments of mudstone occur in this gradational zone. The lower contacts of most sandstones are sharp and show a variety of sole markings including flute casts, groove casts, bounce casts, and worm borings. Palaeocurrent studies based on these structures indicate that currents flowed to the southeast. Graded bedding is not common and reverse grading occurs almost as frequently as normal grading. The sandstones are well washed, well sorted, and consist of angular grains. The conglomerate forms less than 10 percent of the sequence. It is poorly sorted, well graded, and occurs in beds averaging 2 feet (60 cm.) thick. The conglomerate beds are notably thicker, coarser, and more numerous lower in the sequence. The lower contacts are sharp, the upper contacts gradational. The conglomerate consists of about 40 percent matrix

and 60 percent pebbles and cobbles that have a maximum diameter of 3 inches (7·6 cm.) and form a discontinuous framework.

The second lithologic type occurs mainly on the northeastern side of the Macleay River where the sections along the Kempsey-Willawarrin road suggest the presence of at least 3,000 feet (900 m.) of rock.

Lithic sandstone forms about 40 percent of the unit and occurs in beds 1 inch to 4 feet (2·5 cm. to 1·2 m.) thick. The contacts of the beds are sharp. Worm borings, worm trails, and minor slump folds occur in the laminated sandstone. The massive beds are well jointed. The sandstone varies from dark to light grey depending on the carbon content. The mudstones occur in both massive and laminated beds from 0·5 inch (1·3 cm.) to over 3 feet (0·9 m.) thick. Sedimentary structures are common and include open-cast folds, low-angle cross-beds, boudins, scour and fill structures, and both worm borings and worm trails. Current structures suggest a source area to the north. The mudstone is black, grey, or dark green. The conglomerate, which has a discontinuous framework of angular to rounded pebbles, occurs in massive beds from 1 to 100 feet (0·3 to 30 m.) thick.

The sediments are structurally separated from the Parrabel Anticline by the Parrabel Fault complex and subsequently no evidence as to their age is available from superposition. They bear no lithologic similarities to any rocks of known Carboniferous age along the full length of the Manning-Macleay region. However, the sediments of both units contain an extremely high proportion of vitric volcanic fragments as do rocks of known Permian age. This suggests that the rocks were at least derived from the same source as the Permian rocks, and since there is an abrupt change in the composition of the volcanic fragments at or near the Permian-Carboniferous boundary it seems possible that they are Permian in age. The only fossils known definitely to come from the rocks northeast of the Parrabel Fault were found in a small aggregate quarry 16 miles (26 km.) to the north of Kempsey on the Pacific Highway (30° 56·2′ S, 152° 56·5′ E, Bellbrook Military Map Sheet 325/4). The fauna occurs in a fine-grained conglomerate and consists mainly of bryozoa.

Sedimentary Rocks northwest of Mackenzies Creek Fault

The sediments of the northwestern portion of the area consist of highly deformed mudstone, sandstone, and stretched pebble conglomerate. Remnant bedding is present but difficult to see at most localities. Some of these rocks, particularly the stretched pebble conglomerates, show marked similarities with the sediments of the Parrabel Beds. Comparison of the rocks in this area with rocks further north indicates that they have suffered considerably less deformation. The sediments further to the north bear no trace of bedding and show evidence of several periods of deformation.

Sedimentary Rocks southwest of Kunderang Fault

The undifferentiated Palaeozoic rocks in the southwestern corner of the area mapped are separated from the Parrabel Anticline by the Kunderang Fault. These rocks are well-bedded grey and white chert and red jasper that bear a marked similarity to the sediments of the Wooloomin Beds (Benson, 1912 ; Crook, 1961) farther west near Tamworth. Similar sediments were described by Voisey (1934, p. 335) from the Hastings district further south.

High Level Gravels

Deposits of alluvial gravel that cap the hills in the Macleay Valley are probably Pleistocene in age (Voisey, 1934) and possibly represent the remnants of one or more terraces. The gravels consist of well-rounded fragments of labile sandstone, black chert, cherty mudstone, red jasper, and white quartz ; locally the gravel consists entirely of rounded white quartz pebbles. The fragments are as much as 6 inches (15 cm.) in diameter and are set in a matrix of sandy material, or, in some cases, well-consolidated clay.

Structure

The lower Macleay region lies within the Eastern Belt of Folds and Thrusts (Voisey, 1959). Deposition of sediment was terminated early in the Permian (Voisey, 1939*b*) by the onset of an orogeny probably equivalent to the Hunter-Bowen Orogeny. The compound structural forms represented on the map appear to be the result of several superposed deformations which took place during this orogeny.

Folds

Most of the folds in the lower Macleay region are broad, open noncylindrical structures complicated to some extent by crossfolding. Where possible beta-axes have been determined for the folds. However, beta-axes do not necessarily

have the same significance for broad open noncylindrical folds as they do for folds of tight cylindrical style, and since their significance is not completely understood they are consequently of value only in comparing adjacent areas and describing gross morphology.

For purposes of description the district has been divided into three sub-districts: the Parrabel Anticline, the Toorooka Sub-district, and the Macleay Sub-district (Fig. 4).

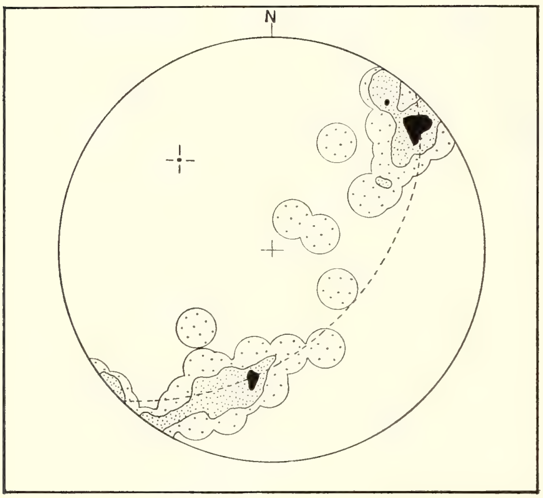

FIG. 4

S-pole diagram of bedding plane attitudes for the Toorooka sub-district. Contours 0%, 10% and 15% per 1% area, 35 readings.

Parrabel Anticline.—The Parrabel Anticline, a large non-cylincrical fold approximately 17 miles (27 km.) wide and at least 20 miles (32 km.) long, dominates the structure of the southwestern part of the district. The fold is bounded by the Kunderang, Mackenzies Creek, and the Parrabel Faults. The steeply dipping limbs and closure region of the fold have been divided into four smaller areas, within each of which the orientation of the bedding planes is statistically uniform. The mean bedding plane attitude has been determined for each area by plotting poles to bedding and a synoptic diagram constructed (Fig. 4) indicates that the beta-axis plunges at 18° to 316°.

The crestal region of the fold is very broad and in detail consists of a series of smaller folds with subparallel and subhorizontal axes. In contrast to the Parrabel Anticline the minor folds are cylindrical concentric structures. The axes of the minor folds parallel the beta-axis of the Parabel Anticline but plunge at only 5°. The axial planes of the minor folds appear to be almost vertical.

Toorooka Sub-district.—The Toorooka Sub-district is bounded in part by the Parrabel Fault and the Macleay Rivers. The sub-district consists of two blocks separated possibly by a fault. The opposing dips of the sediments suggest a faulted syncline, and for this reason bedding attitudes from both sides of the fault were plotted on the same diagram (Fig. 5). The assumption here is that if the fault was not involved in any rotational movement it should be possible to define the beta-axis of the syncline and compare it with that of the Parrabel Anticline. The plot indicates a beta-axis with a plunge of 38° in a direction of 314°. This is comparable in azimuth with the attitude of the beta-axis of the Parrabel Anticline, but of steeper plunge.

Macleay Sub-district.—The Macleay Sub-district includes most of the sediments mapped to the north of the Macleay River. Poor exposures in this area have resulted in a limited amount of data, obtained mostly from two road sections: Kempsey to Willawarrin and Kempsey to Taylors Arm. Using a method similar to that used to study the Parrabel Anticline, the area was divided into three sub-areas and a synoptic diagram constructed for the mean bedding plane attitudes (Fig. 6). This yields a beta-axis with a plunge of 9° in a direction of 284°, which is remarkably similar to the figures obtained for the Parrabel Anticline and Toorooka Subdistrict.

The beta-axes obtained from the Parrabel Anticline, Toorooka Sub-district and Macleay Sub-district suggest that they have the same deformational history. Bedding plane irregularities and limited data from incongruent minor folds suggest that the district might have been folded a second time, although the second folding was much less intense than the main folding.

Faults

The faults of the lower Macleay region are of two types, which appear to have resulted from separate deformations.

The first type characteristically extends for considerable distances and has steeply dipping fault planes, wide crush zones, and extensive splay patterns. The first type includes the Parrabel, Kunderang and Mackenzies Creek faults. The majority of these faults and their

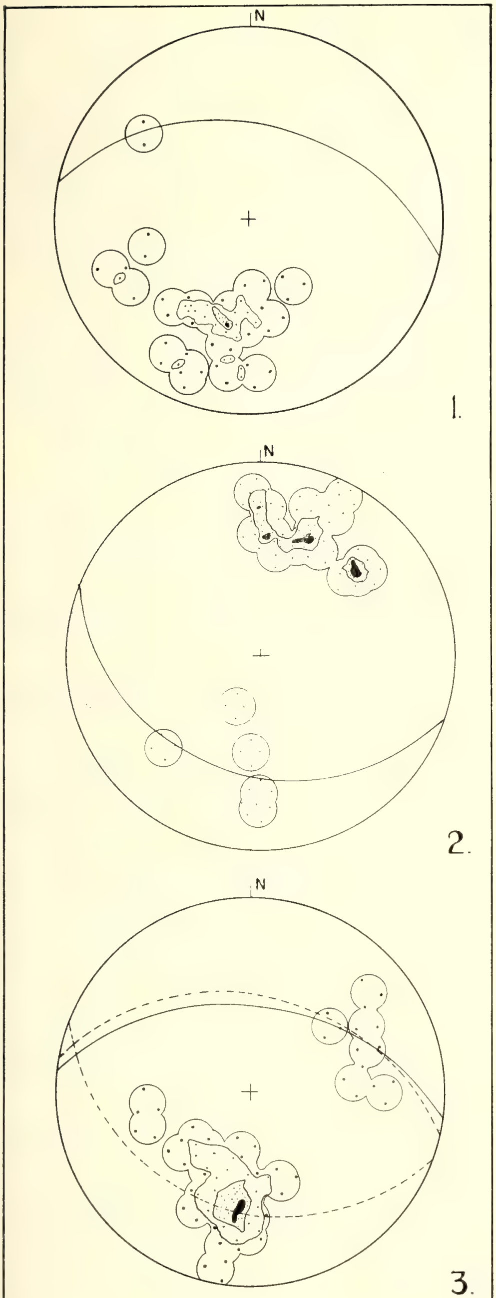

FIG. 5
S-pole diagrams of bedding plane attitudes and synoptic diagram for the Macleay sub-district.
(*a*) Area (1) 20 readings, contours 0%, 10%, 15% and 20% per 1% area.
(*b*) Area (2) 23 readings, contours 0%, 10% and 15% per 1% area.
(*c*) Area (3) 35 readings, contours 0%, 10%, 15% and 20% per 1% area, and also synoptic diagram showing intersection of mean bedding planes.

smaller splay faults trend in two main directions, 115° and 209°. There is no conclusive evidence to suggest the sense of movement on most of the faults. Stratigraphic relations across the faults suggest dip-slip displacements of the order of several thousands of feet on the Parrabel, Kunderang and Mackenzies Creek faults. Horses of Willi Willi Limestone in the crush zone of the Parrabel Fault indicate a strike separation of at least 6,000 feet (1,830 m.).

Faults of the second type intersect and displace the first type. They are shorter and all appear to be dip-slip faults of moderately steep dip, and they have narrow crush zones and displacements that seldom exceed 1,500 feet (460 m.). They strike in two prominent directions, 045° and 010°, and are prominent around the edge of the Parrabel Anticline where they displace the Yessabah Limestone. Few of these faults extend more than 2 miles (3·2 km.), whereas the Parrabel Fault (type one) extends for 26 miles (42 km.)

Correlation

Some earlier workers, particularly Woolnough (1911) and Voisey (1934, 1936, 1945, 1950, 1958), suggested correlations of rock units in the Manning-Macleay region with sequences outside the region. Problems of correlating the sequences come from two sources. First, too little is known of the stratigraphy of the region as a whole. Some formations, notably the Yessabah Limestone, are easily identified at widely spaced localities over the region, others have been recognized only locally. Consequently, many of the formational units established locally may prove inadequate as data from other parts of the region becomes available. Until the stratigraphy of the region is known more completely and the value of the present terminology tested on a local basis, correlations with sections outside the region have little meaning except in a broad sense. The second problem lies in the incomplete knowledge of the palaeontology of the sequence. For example, the only palaeontological evidence available for the lower Carboniferous age of the Boonanghi Beds comes from fragmentary fossils (Voisey, 1934, p. 336) that cannot be identified with any certainty. Further, the two faunas described by Campbell (1962) from the Kullatine Formation and thought to have a well-established age are con-

fused by the occurrence of one of the faunas much in lower in the section in the Majors Creek Formation. The only fauna for which an age can be established readily is the *Eurydesma* fauna in the Yessabah Limestone, and this fauna has not been described in detail.

Consequently it is too early to attempt to correlate in any detail the sequence in the basin with sequences outside the basin.

Conclusions

The sediments of the Macleay district have been divided into six litho-stratigraphic units. Recognition of some of the units, particularly the Carboniferous units, might prove difficult farther south, for, as previously mentioned, the depositional basins appear to deepen considerably in this direction so that turbidites occur much higher in the sequence to the south than they do in the north. Further changes will be made as the palaeontology of the sequence becomes more completely known. These difficulties will be particularly important in any consideration of the stratigraphic position of the sediments to the northeast of the Parrabel Fault and in any consideration of correlations made outside the Manning-Macleay region.

Deposition of the sediments appears to have been terminated early in Permian time by an orogeny probably equivalent to the Hunter-Bowen Orogeny. The main axis of folding plunges at approximately 18° in a direction 316°, but the evidence is insufficient to define a second weaker axis. Two distinct sets of faults are known, one intersecting and displacing the other. The first fault type has steeply dipping fault planes with wide crush zones and extensive splay patterns. These faults extend for as much as 26 miles (42 km.). The second set of faults, which cuts the first, has fault planes with a moderately steep dip, narrow crush zones and small dip-slip displacements. Few of these faults extend for more than two miles (3·2 km.).

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Stratigraphy and Structure of the North-East Part of the Barrier Ranges, New South Wales

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ABSTRACT—The succession of beds outcropping along the axis of the Caloola Syncline, between Sturt's Meadows and Nundooka is described. The lowermost strata are Upper Proterozoic beds of the top part of the Torrowangee Group and they consist of shales, dolomites and tillites overlain by shales and quartzites with a few dolomites. Detailed geological mapping has led to a subdivision of this part of the Torrowangee Group into several rock units, and has shown an unconformable relationship with overlying strata both of (?) Cambrian and of (?) Upper Devonian age.

A thick sequence of (?) Upper Devonian quartzose sandstones and associated sediments of a red-bed facies has also been mapped. These are apparently the marginal beds of the molasse phase of the Lachlan Geosyncline.

Small deposits of (?) Lower Tertiary sediments occur, and these are overlain by widespread remnants of silcrete, and younger deposits of ferricrete and kunkar. The eastern edge of the area is covered by substantial deposits of Quaternary age, mainly alluvial silt and clay.

Introduction

The area studied lies athwart the Silver City Highway some 60-70 miles north-east of Broken Hill between Nundooka and Sturt's Meadows homesteads and is about 300 square miles in extent. Geological mapping on a scale of 20 chains to one inch was carried out over the bulk of the area, with photo-interpretation to complete the coverage. The base map was compiled from aerial photographs, since no map is available on a scale of more than 1 : 250,000. This work formed the graduation theses of the authors, and was completed in January, 1967.

The area is at the eastern edge of the North Barrier Ranges. It consists of ridges and hills rising to 1043 feet above sea level at "Bluff" Trig Station, but with average relief of less than 500 feet. To the east of this high ground a flat plain extends some 25 miles to the Bynguano Range at Mootwingee. Most of the ridges are formed by more resistant strata and can be readily related to the geology of the area. Because these strata are folded in the Caloola Syncline they form distinctive curved outcrop patterns such as at the Bluff near Sturt's Meadows, with dip slopes often clearly distinguished.

Drainage is generally to the north-east and to the east from the higher ground of the ranges. Caloola Creek, Fowler's Gap Creek, Sandy Creek and Nundooka Creek are the most important drainage channels and carry water to Lake Bancannia 15 miles to the north-east of the area mapped. The streams flow only intermittently and are dry for most of the year. Most are heavily lined with gum trees, a probable indication of a higher water table along their courses.

The climate is semi-arid with a rather variable rainfall, but averages less than 8 inches per year. The distribution of rain is irregular and not confined to any particular season. The temperature ranges from over 100 degrees Fahrenheit in summer to less than 40 degrees Fahrenheit in winter, often with a substantial diurnal variation.

Previous Work

Sir Douglas Mawson (1912) named the "Torrowangee Series" and recognized its unconformity with the intensely metamorphosed "Willyama Series". His work was followed in 1922 by that of E. C. Andrews who noted the "Torrowangee Series" and some Palaeozoic beds in the area north of the Broken Hill orebodies.

A substantial contribution was made by E. J. Kenny (1934) in which strata near Fowler's Gap are described and the regional geology of the West Darling District is discussed.

The major structural elements were named by King and Thompson (1953) and further work by Thompson is shortly to appear in the "Geology of N.S.W." a publication of the Geological Society of Australia.

Geological maps on a scale of 1 : 250,000 are concurrently in preparation by the Geological Survey, N.S.W. Dept. of Mines. The Cobham Lake Sheet has been published and the Broken Hill Sheet is in preparation. Data from the present investigation is to be included in the Broken Hill geological map.

Structure

The Torrowangee Group north of Euriowie is folded into a series of anticlines and synclines as shown on the accompanying map (Fig. 3). King and Thompson (1953) give details of how these folds fit into the structural pattern of the Broken Hill District, and name the Caloola Syncline, Sturt's Meadows Anticline and Flood's Creek Syncline. Further folds and faults have been mapped by the Geological Survey, N.S.W. Dept. of Mines for the Broken Hill 1 : 250,000 Sheet. The area discussed in this paper lies along the Caloola Syncline and embraces part of the Sturt's Meadows Anticline. An unnamed anticline between the Caloola and the Flood's Creek Synclines has some influence on the Proterozoic beds in the north-west of the area.

The fold axes strike generally north-west, parallel to the unconformity with the Willyama Complex, but the strike becomes more northerly away from this feature. Several faults close to the strike of these fold axes were mapped by the authors and by the N.S.W. Geological Survey. One of these named the Nundooka Creek Fault occurs on the eastern edge of the rock exposure. The strike of this fault, like that of the fold axes, changes from north-westerly to northerly away from the area of the Willyama Complex. Similarly, the lines of the major unconformities, the Willyama-Torrowangee and the Proterozoic-Devonian lie in a north-westerly direction.

The Caloola Syncline is a south plunging fold outlined by quartzite marker horizons. The dips on its flanks reach 70 degrees but tend to lessen towards the fold axis. Faulting within the syncline is shown by offset of quartzite beds. These faults are of relatively small displacement in comparison with the Nundooka Creek Fault, and tend to strike symmetrically about the fold axis. They are probably related to the development of the syncline.

The Sturt's Meadows Anticline lies to the west of the Caloola Syncline. It plunges to the south with its axis parallel to that of the Caloola Syncline and is traced out clearly by beds of dolomite. To the north-west, beyond the area mapped, this anticline appears to be truncated by a major fault (G. Rose, pers. comm.). Dips recorded on the flanks of the fold are generally of smaller angle than on the Caloola Syncline.

A vertically dipping plane cleavage is developed in the Proterozoic folds. It is apparent in the shales of the sequence as a slaty cleavage, and in the quartzites and carbonate rock as a parallelism of crystalline material. The usually straight cleavage in the shale is distorted in places by chevron folds, due, perhaps, to local faulting. A set of joints occurs at right angles to this cleavage, due to tension in folding. Quartz veins fill these joints and also cut the quartzites, dolomites and shales in other more random directions.

Three dykes of altered andesite occur near the Sturt's Meadow's Anticline. The strike of these coincides with that of the tensional jointing described above.

In the core of the Caloola Syncline a slight angular unconformity separates the Torrowangee Group from beds of probable Cambrian age. These (?) Cambrian strata are gently folded into a syncline. Another marked angular unconformity separates the Proterozoic from Devonian strata.

The Nundooka Creek Fault is a normal fault with a steep dip to the east. It is downthrown to the east and immediately at the fault plane the beds of Devonian sandstone dip at a very steep angle. The amount of displacement is not known, owing to the lack of suitable stratigraphic markers, but it is clearly quite considerable. Its position is recognizable in the northern part of the area by truncation of beds, but in the centre near Fowler's Gap it can be detected only by dip and strike changes in the Devonian sandstone. However the physiographic expression of the fault line is clearly visible on aerial photographs and in the field.

Along a zone on each side of the actual fault the Devonian sandstones are heavily criss-crossed with veins of recrystallized quartz, which probably represent the initial stages of silica remobilization prior to quartz veining and is associated with the stresses produced by fault.

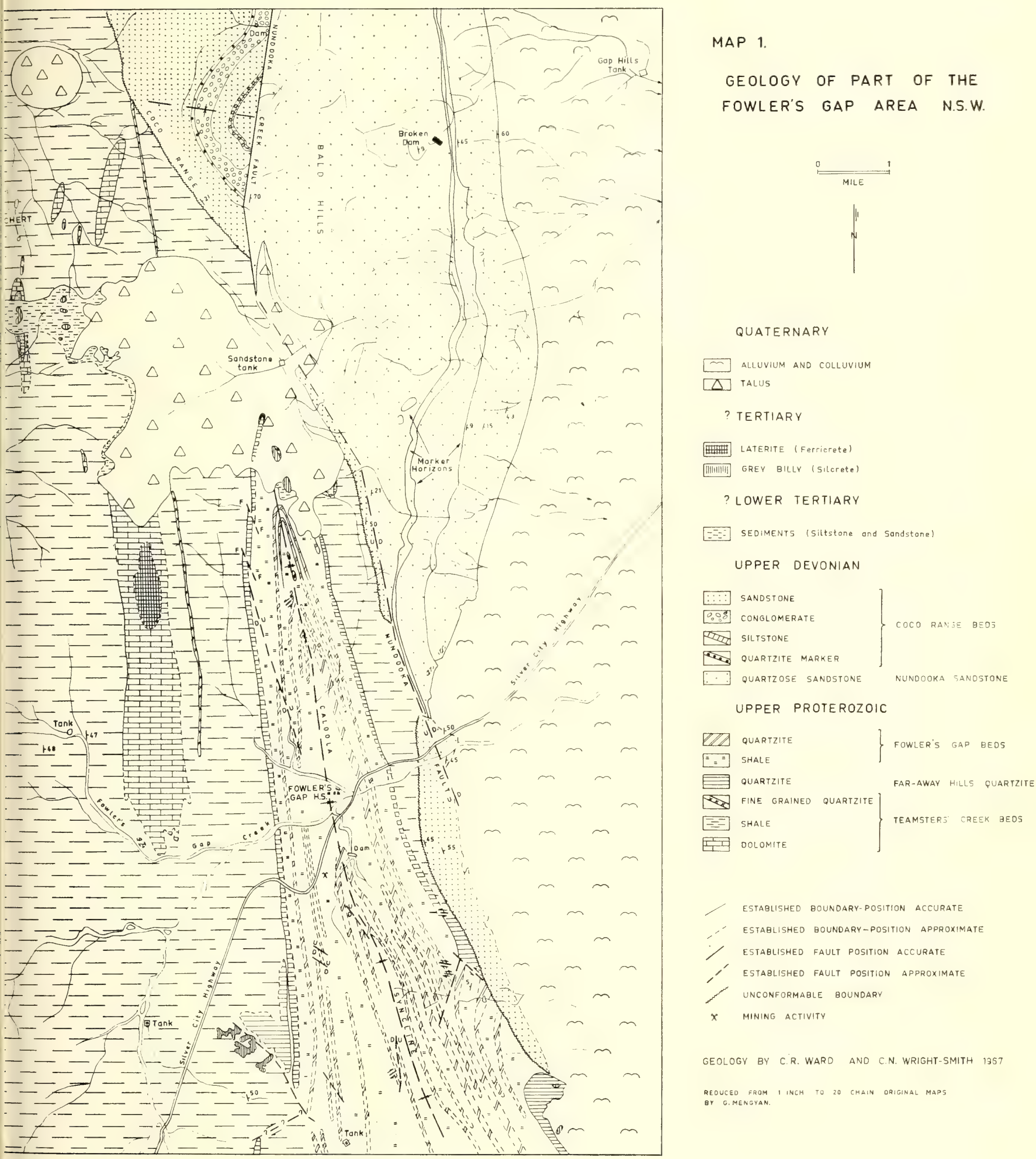
MAP 1.
GEOLOGY OF PART OF THE FOWLER'S GAP AREA N.S.W.
0 1
MILE
N
QUATERNARY
ALLUVIUM AND COLLUVIUM
TALUS
? TERTIARY
LATERITE (Ferricrete)
GREY BILLY (Silcrete)
? LOWER TERTIARY
SEDIMENTS (Siltstone and Sandstone)
UPPER DEVONIAN
SANDSTONE
CONGLOMERATE
SILTSTONE
QUARTZITE MARKER
QUARTZOSE SANDSTONE
UPPER PROTEROZOIC
QUARTZITE
SHALE
FOWLER'S GAP BEDS
QUARTZITE
FAR-AWAY HILLS QUARTZITE
FINE GRAINED QUARTZITE
SHALE
DOLOMITE
TEAMSTERS' CREEK BEDS
ESTABLISHED BOUNDARY-POSITION ACCURATE
ESTABLISHED BOUNDARY-POSITION APPROXIMATE
ESTABLISHED FAULT POSITION ACCURATE
ESTABLISHED FAULT POSITION APPROXIMATE
UNCONFORMABLE BOUNDARY
MINING ACTIVITY
GEOLOGY BY C.R. WARD AND C.N. WRIGHT-SMITH 1967
REDUCED FROM 1 INCH TO 20 CHAIN ORIGINAL MAPS BY G. MENGYAN.
CHERT
Dam
NUNDOOKA CREEK FAULT
COCO RANGE
BALD HILLS
Broken Dam
Gap Hills Tank
Sandstone tank
Marker Horizons
NUNDOOKA FAULT
CALOOLA
FOWLER'S GAP H.S.
Fowler's Gap Creek
Tank
Silver City Highway
MAP 2 ADJOINS

FIG. 1

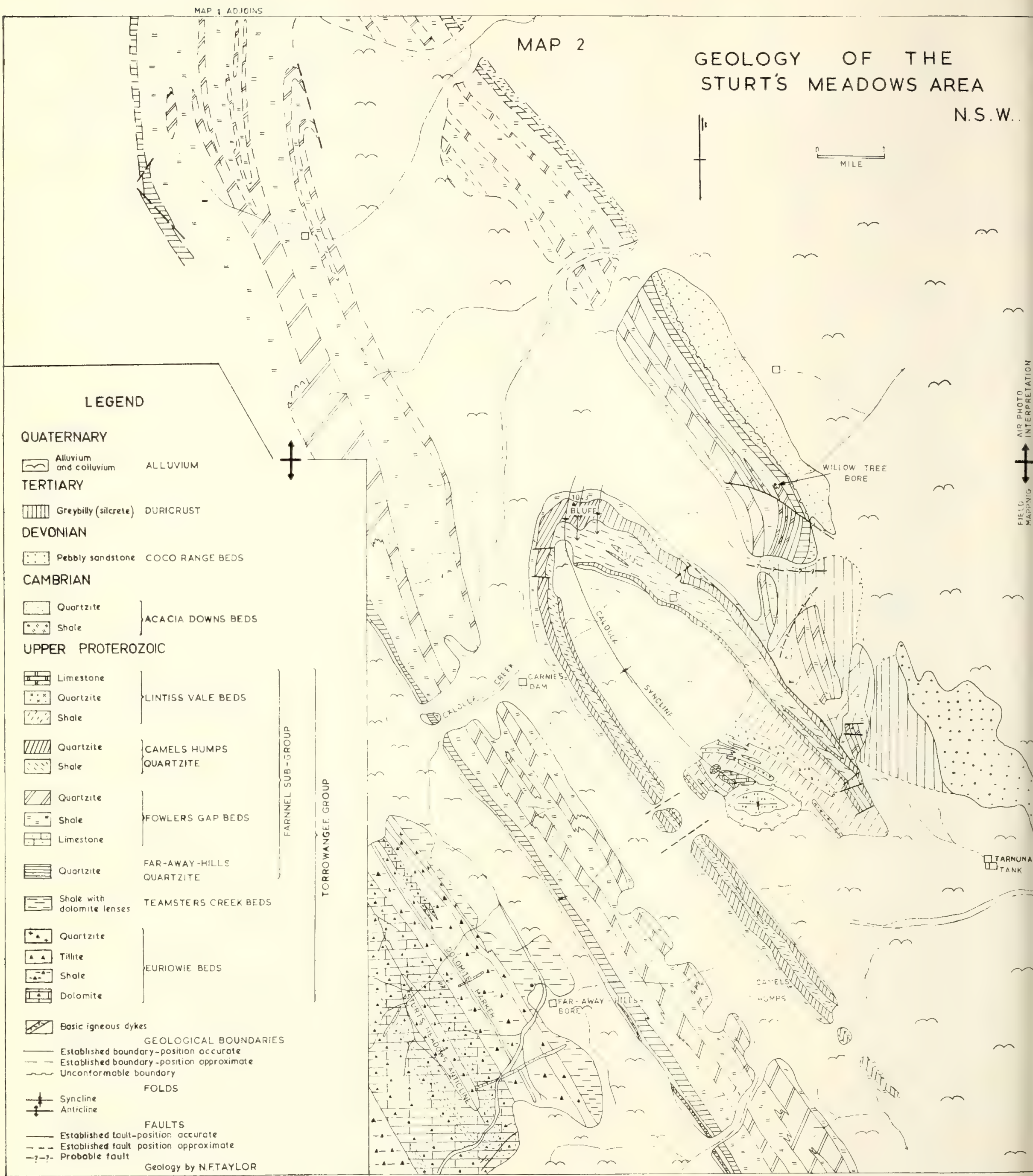
MAP 1 ADJOINS
MAP 2
GEOLOGY OF THE STURT'S MEADOWS AREA N.S.W.
MILE
AIR PHOTO INTERPRETATION
FIELD MAPPING
WILLOW TREE BORE
BLUFF
CALOOLA SYNCLINE
CALOOLA CREEK
CARNIES DAM
TARNUNA TANK
CAMELS HUMPS
FAR-AWAY-HILLS BORE
DOLOMITE MARKER
STURTS MEADOWS ANTICLINE
LEGEND
QUATERNARY
Alluvium and colluvium ALLUVIUM
TERTIARY
Greybilly (silcrete) DURICRUST
DEVONIAN
Pebbly sandstone COCO RANGE BEDS
CAMBRIAN
Quartzite
Shale
ACACIA DOWNS BEDS
UPPER PROTEROZOIC
Limestone
Quartzite
Shale
LINTISS VALE BEDS
Quartzite
Shale
CAMELS HUMPS QUARTZITE
Quartzite
Shale
Limestone
FOWLERS GAP BEDS
Quartzite FAR-AWAY-HILLS QUARTZITE
Shale with dolomite lenses TEAMSTERS CREEK BEDS
FARNELL SUB-GROUP
Quartzite
Tillite
Shale
Dolomite
EURIOWIE BEDS
TORROWANGEE GROUP
Basic igneous dykes
GEOLOGICAL BOUNDARIES
Established boundary-position accurate
Established boundary-position approximate
Unconformable boundary
FOLDS
Syncline
Anticline
FAULTS
Established fault-position accurate
Established fault position approximate
Probable fault
Geology by N.F.TAYLOR

Fig. 2

Similar, but less intense veining also occurs along the axes of the gentle folds in these sandstones.

The Upper Devonian strata are folded into an easterly plunging syncline in the Coco Range, and a broad anticline east of Sandstone Tank. In the Coco Range the dip of the beds at the unconformity with the Proterozoic strata is 10 to 20 degrees to the north-east, and near Willow Tree Bore in the south it is also 20 degrees north-easterly. Dips of 45 to 60 degrees at the unconformity were noted, immediately east of Fowler's Gap, but these are probably due to the Nundooka Creek Fault.

East of the Nundooka Creek Fault the Devonian strata of the downthrown block show dips increasing from 9 degrees to 60 degrees easterly, until they are overlapped by Quaternary sediments.

Folding of the Proterozoic Strata to form the Caloola Syncline and Sturt's Meadows Anticline commenced before deposition of the (?) Cambrian strata of the Acacia Downs Beds. The generation of faults within the syncline mentioned above took place probably at the same time, but at least before the Upper Devonian beds were deposited. The Upper Devonian Coco Range Beds and Nundooka Sandstone were

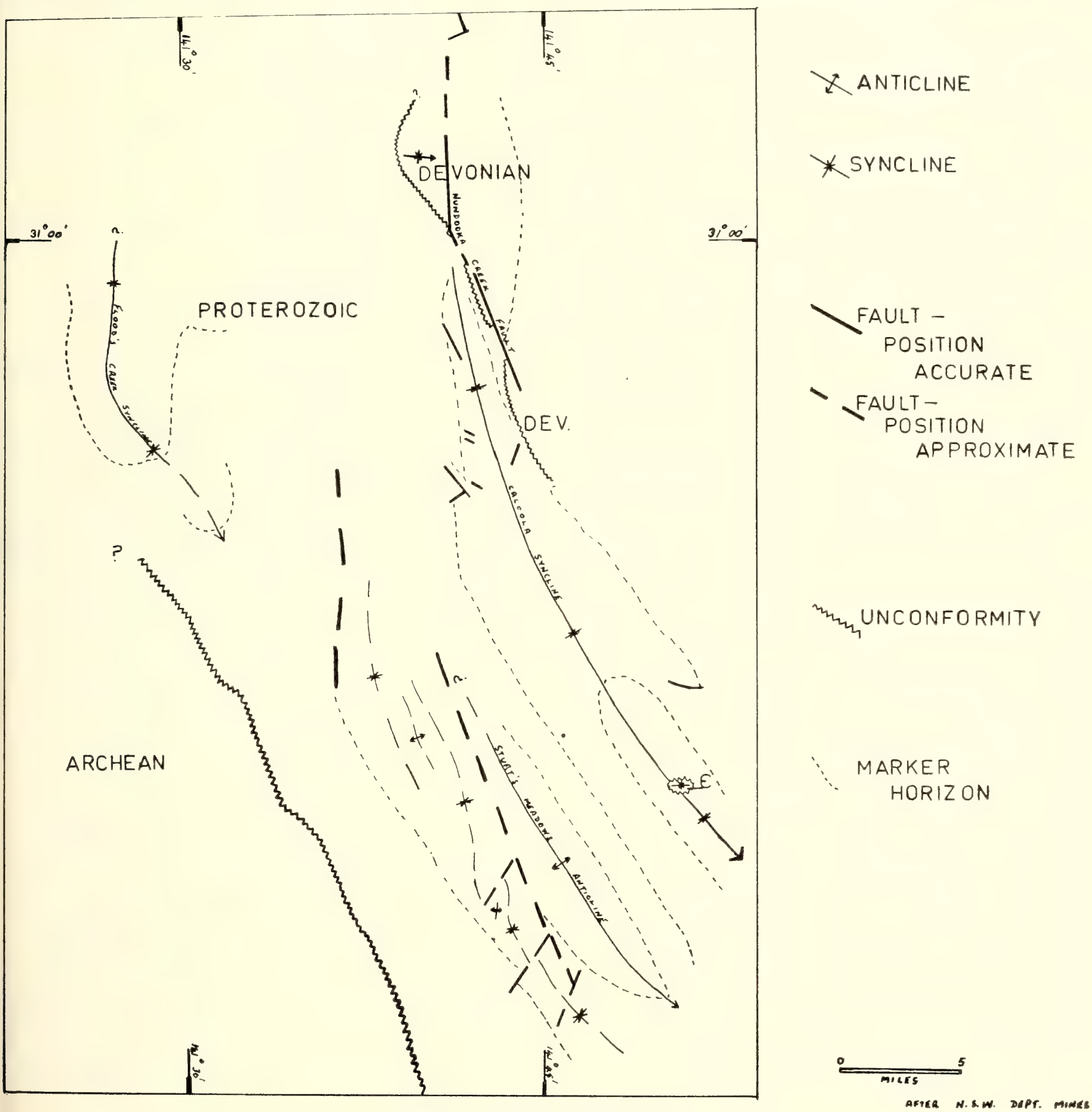

Fig. 3.—Structural elements.

deposited and folded prior to the formation of the Nundooka Creek Fault.

Since this faulting there have been slight changes in climate or elevation with silcrete and talus deposits having formed and being eroded under the present physiographic conditions.

Stratigraphy

The succession of strata discussed below in detail is based on the field work of the authors. Seven rock units are recognized and named by the authors, and two others are mapped which have been named by other workers.

Strata of the Upper Proterozoic Torrowangee Group are unconformably overlain by strata thought to be Lower Cambrian in age. Sandstones and some shales of (?) Upper Devonian age also overlie the Precambrian rocks with a strong angular unconformity, but nowhere within the area mapped are these strata in contact with the Cambrian beds.

Horizontal beds of sandstone and siltstone thought to be Lower Tertiary age are found in one small part of the area. Scattered residuals of duricrust in the form of silcrete and ferricrete also occur, and there are substantial deposits of Quaternary fluviatile, aeolian and colluvial sediments.

The assignment of ages to most of the rock units mapped is only on a tentative basis, because very few fossils were found in the entire sequence. The rock units are summarized in Table 1.

TABLE 1
Stratigraphy

Era	Epoch.	Group	Formation	Lithology	Thickness (feet)	Remarks
CAINZOIC	Quaternary		Alluvium	Silt and clay and some sand	300	Penetrated by bores
	Upper Tertiary ?		Duricrust	Silcrete and some ferricrete	10	See also Langford-Smith and Dury (1965) and Dury (1966)
	Lower Tertiary ?			Sandstone and siltstone	200	Age uncertain—similar sediments to the north
PALAEOZOIC	Upper Devonian ?		Nundooka sandstone	Quartzose sandstone and Orthoquartzite	3,500	Downthrown block of Nundooka Creek Fault Named by authors
			Coco Range Beds	Quartzose sandstone and orthoquartzite, pebbly sandstone, red and green shale	2,500	Upthrown block of Nundooka Creek Fault –Unconformably overlies Proterozoic Named by authors
	Lower Cambrian ?		Acacia Downs Beds	Quartzite and shale		Fossils reported but not found by authors unconformably overlies Proterozoic Named by B. Warris
PRECAMBRIAN	UPPER PROTEROZOIC	TORROWANGEE GROUP; FARNELL SUB-GROUP	Lintiss Vale Beds	Cleaved shale with quartzite and limestone	4,000	Named by authors
			Camels Humps Quartzite	Quartzite with shale	700	Marker horizon Named by authors
			Fowler's Gap Beds	Shale and quartzite with few limestone lenses	10,000 (approx.)	Named by authors
			Faraway Hills Quartzite	Quartzite	300	Marker horizon Named by authors
			Teamsters' Creek Beds	Shale with dolomite lenses	6,000 (approx.)	Named by authors
			Euriowie Beds	Shale, dolomite and tillite		Named by N.S.W. Dept. Mines for Broken Hill 1 : 250,000 Sheet. Rests conformably on remainder of Proterozoic sequence

Upper Proterozoic

Torrowangee Group

The Torrowangee " Series " of Mawson and succeeding workers has been revised as the Torrowangee Group for the Broken Hill 1 : 250,000 Geological map, by the N.S.W. Dept. of Mines. Its constituents formations include those named in this paper and several others cropping out beyond the present areas. A brief summary of the regional stratigraphic succession of the Torrowangee Group as shown on the Broken Hill 1 : 250,000 Geological Map is given below :—

Top	Cambrian and other strata.
Unconformity	
Farnell Sub-Group	Shale and quartzite with minor limestone lenses. See details below.
Teamsters' Creek Beds	Shale with dolomite lenses and tillite-like phases.
Euriowie Beds ..	Laminated tillite-like shale, dolomite and limestone, sandstone and conglomerate.
Yancowinna Beds	Conglomerate, sandstone numerous erratic pebbles and boulders of possible glacial origin ; some limestone.
Pintapah Quartzite	Quartzite, sandstone, pebbly quartzite.
Wilangee Volcanics	Basalt, epidotized basalt.
Unconformity	

Willyama Complex

Only the upper part of this sequence including the Farnell Sub-Group, the Teamsters' Creek Beds and part of the Euriowie Beds are found to crop out in the area mapped.

Details of these stratigraphic units are given below.

Euriowie Beds

The Euriowie Beds are named by G. Rose for the Broken Hill 1 : 250,000 Geological Map. They crop out in the south-west corner of the area mapped in the present study, where they are exposed in the Sturt's Meadows Anticline.

The base of the unit is not seen in this area, but the top is clearly defined. It is taken as the top of the tillite marker horizon, including its laterally equivalent quartzite horizon as mapped on the flank of the anticline.

Dark grey-green shale is the lowest bed and is exposed on the crest of the fold. This is overlain by a sequence of grey-brown dolomite and grey-green shale. The shale often becomes dolomitic and grades into dolomite, especially in the lower part of the section. Dolomite beds are generally less than three feet thick, but they persist for quite some distance along strike and help delineate the structure. It is unfossiliferous with interlocking fine carbonate crystals and is probably recrystallized. These crystals show an apparent elongation which may either reflect bedding or a tectonic preferred alignment.

Shale becomes dominant again above this unit, but dolomite beds are still present. One horizon is particularly prominent. This is made up of ten closely spaced dolomite beds and can be traced as virtually a single unit 30 feet thick for over four miles along strike.

There is a layer of tillite at the top of the Euriowie Beds. This is about 300 feet thick on the eastern flank of the anticline, but on the western side, beyond the area mapped, it thickens to 1,500 feet and is much better exposed. It passes laterally into a quartzite further to the north. The tillite forms a dominant outcrop with many boulders scattered nearby. The rock assemblage displayed in these boulders is extremely heterogeneous with quartzite most abundant. Granite, gneiss, schist, basic igneous rock, shale, slate and limestone also present. The size of these fragments is also highly variable. Excluding those of the matrix, the fragments range from small pebbles and cobbles to boulders and several megaclasts with a maximum dimension of four to five feet. In sympathy with this size variation, the fragments range from sharply angular to sub-rounded and are from flat and platey to sub-spherical in shape.

The tillite is conformable with the rest of the Proterozoic sequence and often shows some degree of bedding. However, the thicker deposit on the western flank of the Sturt's Meadows Anticline is an unbedded mass of dispersed boulders. The boulders and pebbles are set in a matrix of angular sand grains and grey siliceous to blue-green argillaceous material.

Well bedded, thin layers of consolidated gravel, arkosic grit, coarse grained sandstone and quartzite occur throughout the tillite on the eastern limb of the anticline. Sometimes the gravels show several cycles of graded bedding.

The name " tillite " is applied to this rock type because of its appearance in the field. Although no striations were found on them, it is felt that the occurrence of such large boulders of diverse rock types, often separated by a high proportion of matrix is strongly indicative of glacial action. In view of the current importance attached to Precambrian

glaciation on a world-wide basis (Nairn, 1964), further work on the origin of these beds may be justified.

The tillite becomes more shaley and the boulders more sporadic as it grades upwards into the Teamster's Creek Beds.

Teamsters' Creek Beds

This unit is named by the authors after Teamsters' Creek, a water-course west of Fowler's Gap Tank. It conformably overlies the tillite horizon at the top of the Euriowie Beds, and is in turn overlain by the prominent Faraway Hills Quartzite.

It is exposed extensively along the western side of the area mapped and consists mainly of shales with limestone and dolomite lenses.

The boundary between the Teamsters' Creek Beds and the Euriowie Beds is exposed in the south-western corner of the area mapped. North and west of Fowler's Gap its area of outcrop becomes more extensive due to the presence of an anticline and possible faulting between the Caloola and Flood's Creek Syncline.

The shale is generally grey-green in colour, but in places becomes red-brown and buff. White calcareous phases are also encountered. A strong axial plane cleavage has been developed in the shale, and recrystallization has undoubtedly obscured much of the bedding. Microscopic and X-ray determination of the mineral assemblage indicates that metamorphism of the rock approached greenschist facies, thus the term " slate " should perhaps be applied. However shale is used in this text to maintain uniformity in definitions with other workers, especially those concerned with the Adelaide Geosyncline in South Australia. In some localities the strata are more intensely deformed, with phyllites of silky lustre due to the muscovite flakes and a dark green colour due to the presence of chlorite, often developed. This is especially noticeable near the Nundooka Creek Fault.

Throughout the Teamsters' Creek Beds, but especially in the north-west corner of the area, the shales become tillitoid. Boulders, pebbles and sand-size grains of quartz, quartzite and other rock fragments are set in a fine grained lepidoblastic micaceous matrix. The boulders range up to two feet across and generally appear more rounded than the grains. The fragments are poorly sorted but occasionally elongated boulders are aligned parallel indicating either bedding or rotation association with the development of slaty cleavage.

It is thought that the poor sorting and sporadic development of this coarse material in an otherwise fine grained shale is indicative of glacial action with possible ice-rafting, rather than fluviatile deposition of conglomerate. Beds of probable tillite occur lower down in the Torrowangee Group, especially at the top of the Euriowie Beds and in the Yancowinna Beds.

Dolomites and limestones occur as lenses throughout the sequence, and are often interbedded with white or grey-green shales. The dolomites are generally buff in colour and contain a high proportion (about 45%) of quartz. They are cut by numerous quartz veins and it is suggested that much of the silica in these dolomites is due to replacement of carbonates.

The limestones on the other hand are dark grey in colour and occur as only small lenses. They are largely free of quartz veins and contain almost no material other than carbonate.

Major lenses of dolomite are shown on the map. As well as these, there are minor occurrences of limestone and dolomite throughout the shales of the Teamsters' Creek Beds.

Two small outcrops of black, fine grained chert-like rock occur in the north-west of the area. These are comprised of quartz and muscovite, but their origin is uncertain. One of these lenses is very heavily veined with white quartz, giving a banded appearance.

A long prominent ridge of white, fine grained rock is mapped just west of Fowler's Gap. This is composed of recrystallized quartz less than 0·05 mm. in diameter with an interlocking fabric. It may represent a completely silicified bed of dolomite, although its shape is different from that of any other dolomite bed in the area, or it may be a deposit of silica (e.g. chert) which has been recrystallized. It does not appear to be intrusive as no contact effects are noted in the surrounding shale.

The Teamsters' Creek Beds are about 6,000 feet thick in the south-west of the area where both top and base are exposed. Structural complications to the north prevent any reliable estimate of thickness in the remainder of the area mapped.

Farnell Sub-Group

Conformably overlying the Teamsters' Creek Beds is a sequence of quartzite beds and cleaved shale with subordinate limestone lenses. It is distinctly different from the underlying strata of the Teamsters' Creek and Euriowie Beds

because no continuous beds of quartzite are found in the latter units.

The Sub-Group takes its name from the County of Farnell, Western Division in which the area lies. The unit is subdivided, as follows, into four formations, two of which are prominent marker horizons.

4,000 ft.	Lintiss Vale Beds	Shale with interbedded quartzite and dolomite.
900 ft.	Camels Humps Quartzite	Marker horizon — two quartzite beds separated by shales.
10,000 ft.	Fowler's Gap Beds.	Shale with numerous quartzite beds and subordinate limestone lenses.
300 ft.	Faraway Hills Quartzite	Marker horizon—single quartzite bed containing minor shale lenses.

The most complete section of the Farnell Sub-Group is exposed in the Caloola Syncline, as shown on the accompanying maps. Although some erosion may have occurred, the top is at present defined as the unconformable boundary with the overlying (?) Cambrian strata in the core of the syncline. The Broken Hill 1 : 250,000 Geological Map shows a further occurrence of these quartzites in the Flood's Creek Syncline near Mt. Westwood, north-west of the present area.

Faraway Hills Quartzite

The lowest formation in the Farnell Sub-Group is a very prominent marker horizon consisting of a bed of medium grained quartzite 200 to 300 feet thick with occasional minor shale lenses up to 20 feet thick. It forms the highest of the ridges along both limbs of the Caloola Syncline and crops out east and west of the Fowler's Gap Homestead. King and Thompson (1954) show it as a marker horizon for the Caloola Syncline and refer to it as " Thirty Mile Ridge ".

The formation takes its name from the Faraway Hills Bore, in the southern part of the area, near its outcrop.

In thin section the quartzite is composed of 90% to 95% quartz, with some opaque iron oxides and traces of muscovite. The quartz shows some evidence of recrystallization and in places a cataclastic texture is present. The grain-size is up to 0·4 mm., but some of the brecciated fragments are as small as 0·01 mm. Recrystallization and brecciation have obliterated most of the characteristics of the original sedimentary rock. In some specimens a shearing effect is shown by parallelism of quartz crystals and increased brecciation. Both the sheared and the more massive types are clearly recognizable in hand specimens.

Fowler's Gap Beds

Between the prominent marker beds of the Faraway Hills and the Camels Humps Quartzites is a sequence of interbedded quartzite and cleaved shale to which the name Fowler's Gap Beds is given. Fowler's Gap Station, from which the name is derived, lies in the centre of their outcrops on the Silver City Highway. The base and the top of the unit are defined by the top of the Faraway Hills Quartzite and the base of the Camels Humps Quartzite respectively.

The quartzites are similar in appearance to the Faraway Hills Quartzite described above, although about 5-10% of felspar (usually microcline), is present. The beds vary in thickness from six inches to six feet, but are very irregular and are often obscured by talus. They are often intimately interbedded with shale and the quartzite thickens, thins, splits and pinches out quite frequently. Areas shown on the map as quartzite usually include a considerable amount of shale, as lenses, or often as separate beds.

Shale makes up most of the rest of the unit. It is usually light grey-green in colour although buff and white types develop. At the top of the Fowler's Gap Beds just below the Camels Humps Quartzite at " Bluff " Trig Station the shale contains several thin bands, rich in goethite, haematite and calcite. It is thought that this represents " red-bed facies " development due to erosion of lateritic material in the source area. A similar horizon is reported by Thompson (1964) underlying the Pound Quartzite in South Australia.

Sedimentary structures suggestive of worm tracks are seen in the shale about two miles north-west of Willow Tree Bore. Smooth curved tracks about one eighth inch deep are associated with hemispherical pits of irregular shape and size.

Small lenses of limestone and dolomite occur throughout the shales. One of these, just west of the Fowler's Gap Homestead is seen to grade laterally through calcareous quartzite to quartzite.

Between Faraway Hills Bore and Camels Humps the Fowler's Gap Beds are about 10,000 feet thick. Their area of outcrop around Fowler's Gap Homestead is greater than would be expected due to a reduction of dip angle in the synclinal limbs. Hence the quartzite beds become separated in outcrop by a greater distance and so appear to be more numerous than further to the south.

Camels Humps Quartzite

This is a very prominent marker horizon tracing out the outline of the Caloola Syncline east of Sturt's Meadows. The formation lies conformably between the Fowler's Gap Beds and the Lintiss Vale Beds and is readily recognized by virtue of its prominent outcrop. The best development of quartzite is near the "Bluff" Trig Station where the steep slopes expose the full section. The name is taken from the locality "Camels' Humps", a ridge to the east of Faraway Hills Bore.

It is not a single mass of quartzite but consists of two major and one less prominent quartzite beds interbedded with shales. A typical section as exposed near the "Bluff", is as follows (thicknesses approximate).

Top:

100 feet.	Quartzite.
300 feet.	Shale.
250 feet.	Massive Quartzite.
150 feet.	Shale.
150 feet.	Massive Quartzite.

Base.

This gives a total thickness of some 900 feet. The lower two quartzites are shown as one unit on the map, and appear as a single ridge in the field. The top quartzite bed is included with the Camels' Humps Quartzite because of its lithological similarity to the main ridge-forming bed and its persistence compared to those of the Lintiss Vale Beds.

Some current markings are occasionally exposed on bedding planes of the massive quartzites and clay galls are found in the uppermost minor quartzite. These clay galls are markedly spherical, dark red inclusions in massive quartzite. They are about one to two inches in diameter and number about two or three to the square yard of exposed rock surface.

Lintiss Vale Beds

Overlying the Camels' Humps Quartzite marker there is a sequence of shales with interbedded quartzites and a dolomite horizon at the top. These are the uppermost Proterozoic sediments in the Caloola Syncline and are unconformably overlain by strata believed to be Cambrian in age.

These are named by the authors the Lintiss Vale Beds after a property a few miles to the south. Although part of the section may have been eroded the formation is approximately 4,000 feet thick and is composed dominantly of shale with lenticular beds of quartzite in the upper half. Colluvial cover between their outcrop and the "Bluff" prevent a more complete study of these beds.

The top of the Lintiss Vale Beds has been taken at the unconformity with the Acacia Downs Beds. Immediately beneath these (?) Cambrian strata a thin dolomitic bed occurs. This horizon is only 40 feet thick and is made up as follows.

Top:

10 feet.	Flaggy Quartzite.
10 feet.	Dolomite.
10 feet.	Quartzite.
10 feet.	Dolomite.

Base.

The dolomites are similar to those of the Teamsters' Creek Beds and form a shallow dipping plateau beneath the (?) Cambrian strata. Some small scale slumping has been observed in these sediments.

The shales are buff-brown in colour, especially near the top of the sequence, as opposed to the more common grey-green colour typical of the rest of the Torrowangee Group in the area.

(?) Cambrian

Acacia Downs Beds

Resting with a slight angular unconformity on the Lintiss Vale Beds is a sequence 200 feet thick of light green-brown shale overlain by 150 feet thick grey quartzite. It is lithologically similar to the rocks of the Torrowangee Group beneath. The Cambrian age assigned to these rocks is based on the reported occurrence of fossilized worm tracks and arthropod trails by Messrs. Fitzpatrick and Johnson of Adelaide (M. F. Glaesner, pers. comm.), but no further specimens were found during the present study.

This formation has been named by B. Warris (unpublished) after the property "Acacia Downs" to the south. These sediments are only found in small areas at the centre of the Caloola Syncline, west of the Tarnuna Tank, with an extent of about a square mile.

Some cross bedding has been noted in the quartzite, which has both massive and flaggy phases. Sole markings, both tool and current types, are relatively abundant.

Correlation of the Proterozoic

The Upper Proterozoic beds of the Torrowangee Group are separated from the type area succession in the Adelaide district by the Willyama Block, which acted as a positive tectonic element during Sturtian and Marinoan time (Sprigg, 1952), and from which much of the detritus was derived. The units in the area mapped can be correlated with the upper part of the sequence in the Adelaide Geosyncline by virtue of their environmental similarity, although they do not attain the great thickness of the type section. Table 2, gives a summary of the proposed correlation, using the rock unit names of Thompson *et al.* (1964) for the North Flinders Range.

In the Sturt's Meadows—Nundooka area, the most striking feature of the Torrowangee Group is the change from shales, dolomites and tillites of the Euriowie and Teamsters' Creek Beds to the persistent beds of quartzite in the Farnell Sub-Group. This is the same as in the Adelaide Geosyncline where the glacial character of the Umberatana Group gives way to the quartzites and shales of the Wilpena Group (Thompson *et al.*, 1964).

It is difficult to extend the stratigraphic correlation beyond this and attempt to correlate individual formations, largely because there is no continuous outcrop between the two areas. The Willyama Complex around Broken Hill is thought to have been a cratonic block during the late Precambrian, separating the Adelaide Geosyncline and the Torrowangee Group. Sprigg (1952) describes the derivation of the Sturtian glacials from this block, and it is quite likely to have persisted as a source area throughout the remainder of the Proterozoic. Thus the Willyama Block seems to have been in a position whence sediment was supplied to two depositional areas, at the same time. Any major climatic change or tectonic disturbance in this block would have affected the

Table 2

Stratigraphic Correlation of the Proterozoic Sequence

System	Series	Rock Units				
			North Flinders Ranges (after Thompson *et al.* 1964)			Sturt's Meadows-Nundooka (this paper)
Cambrian	Lower Cambrian		Parachilna Formation			Acacia Downs Formation
			Local disconformity			Unconformity
Adelaide System	Marinoan Series	Wilpena Group	Pound Quartzite	Torrowangee Group	Farnell Sub-Group	Lintiss Vale Beds Camels' Humps Quartzite
			Wonoka Formation Bunyeroo Formation			Fowler's Gap Beds
			A.B.C. Range Quartzite			Faraway Hills Quartzite
			Brachina Formation Nuccaleena Formation			Teamsters' Creek Beds
		Umberatana Group	Yeralina Formation			Euriowie Formation

type of sediment in each depositional area. A change of this type may well be responsible for the cessation of glacial activity and the commencement of deposition of quartzose sandstones which occurs in both the Adelaide Geosyncline and the area mapped. However deposition within each of the two areas was controlled by more local effects, and a sufficiently different sequence was developed in each to make exact correlation difficult.

It should also be noted that in the Adelaide Geosyncline there is an apparently conformable succession from the Proterozoic into the Cambrian, but at Sturt's Meadows there is a distinct angular unconformity between the Lintiss Vale Beds of the Proterozoic and the (?) Lower Cambrian Acacia Downs Beds. It is possible that the top of the Proterozoic sequence in the Caloola Syncline was removed by erosion prior to deposition of the Cambrian strata, and so the succession at present preserved there may not extend completely to the top of the Precambrian as it appears to do in the Adelaide Geosyncline.

Upper Devonian

Resting unconformably on a basement of Proterozoic shale at the eastern edge of the Barrier Range in the area mapped are beds dominantly of quartzose sandstone of probable Upper Devonian age. Previous published information has not recorded any fossils in these beds, but David (1950) regards them as Upper Devonian and probably equivalent to the "Lambian Stage" in eastern N.S.W. Dr. M. J. Rickard (pers. comm.) has recently found some fish plates c.f. *Bothriolepis* sp.) in the sandstones east of Fowler's Gap. These have an age of Middle to Upper Devonian and are probably indicative of fresh water conditions.

The Nundooka Creek Fault separates these beds into two blocks. The western, upthrown block has some lithological differences from the eastern block and the two units are given separate names. Since the fault separates these units along the entire length of their outcrop the full sequence cannot be seen anywhere, although they are probably stratigraphically conformable.

The units recognized are:

Coco Range Beds:—A sequence of quartzose sandstones and conglomerates with red and green-grey siltstones and claystones; this unit immediately overlies the Torrowangee Group with a sharp angular unconformity.

Nundooka Sandstone:—A thick unit almost entirely of quartz sandstones brought down against the Coco Range Beds by the Nundooka Creek Fault.

It is clear that the Nundooka Sandstone overlies the Coco Range Beds but since the fault interrupts the exposure of the sequence no further stratigraphic relationships can be observed in this area, or even to the north, near Nundooka Homestead.

Coco Range Beds

These rest with a marked unconformity on cleaved shale of the Upper Proterozoic Torrowangee Group. They are exposed along the eastern edge of the area but it is in the Coco Range to the north that the most complete sequence is to be seen. The unit is named by the authors after the Coco Range (Cobham Lake, N.S.W. 1 : 250,000 Military sheet grid ref. 469168), where the best development occurs.

At the base where it overlies the Proterozoic some red and green shaly units are exposed. These are in turn overlain by a thick sequence of conglomerates and sandstones. At least 2,500 feet of sediment is exposed in the Coco Range where the sequence is as follows:—(thicknesses approximate only)

Top:—Truncated by Nundooka Creek Fault.

600 feet.	Quartz sandstone.
3 feet.	Green-grey siltstone.
10 feet.	Pebbly sandstone and conglomerate.
300 feet.	Quartz sandstone.
600 feet.	Pebbly sandstone and conglomerate.
4 feet.	Orthoquartzite. (Marker horizon).
900 feet.	Quartz sandstone and orthoquartzite.

Unconformity

Base:—Proterozoic Torrowangee Group.

In lenticular patches above the unconformity exposures of argillaceous material are sometimes seen. A section measured east of Fowler's Gap Homestead at the base of the Coco Range Beds, is as follows:—

Top:—Quartzose sandstone.

2 feet.	Red and green claystone beds.
1 foot.	Red sandstone.
1 ft. 6 inches.	Coarse grit.
10 feet.	Red claystone.

Unconformity

Base:—Proterozoic shale.

Where these beds are not present sandstone rests directly on the Proterozoic. This Devonian sandstone often contains angular fragments of grey-green shale derived from the Torrowangee Group beneath.

The sandstones of the Coco Range Beds are medium grained, fairly well sorted and in places quite flaggy. They contain about 90% quartz and the rest consists of mica and rock fragments set in a matrix of white clay. Some iron oxide, probably authigenic, is also present. Many beds of orthoquartzite about four feet thick persist as distinct horizons both in the Coco Range and Nundooka sandstones. They are much harder than the sandstones described above, with a cemented nature due to secondary enlargement of quartz grains. This diagenetic precipitation of silica appears to have been confined to horizons of less clayey sandstone in the Devonian sequence.

Small hemispherical pits one eighth to one quarter inch in diameter are often seen in the Devonian sandstones. These are left by weathering out of spherical patches, rich in clay, within the sandstone. These clayey patches may be primary or diagenetic; not unlike concretions. Flattened blebs of grey shale also occur within the sandstone. Removal of the shale on exposure leaves polygonal hollows resembling fish plates, but these impressions do not have any regular shape or ornamentation.

The conglomerates contain rounded cobbles and pebbles of white vein quartz, up to four inches across, set in a sand and granule matrix. Although the proportion of pebbles varies, the bulk of the rock consists of pebbly sandstone rather than true conglomerate.

The upper limit of the Coco Range Beds is not clearly defined due to truncation by the Nundooka Creek Fault. However photogeological interpretation of the area to the north indicates that very little more of the sequence is likely to be exposed on the western side of the fault than seen in the area mapped.

Nundooka Sandstone

On the eastern side of the fault, a sequence of at least 3,500 feet of quartzose sandstone is exposed. This is called the Nundooka Sandstone after "Nundooka" Station to the north. The sandstone is very similar to that of the Coco Range Beds, but no conglomerate units were observed in the area mapped. Pebbly bands do occur in places and one very thin bed of green shale is exposed. Orthoquartzite beds similar to those described above occur with secondary enlargement of quartz. Three of these beds are persistent enough to trace as marker horizons over many miles.

The base of the units is obscured due to the Nundooka Creek Fault, and the top is covered by extensive deposits of alluvium to the east.

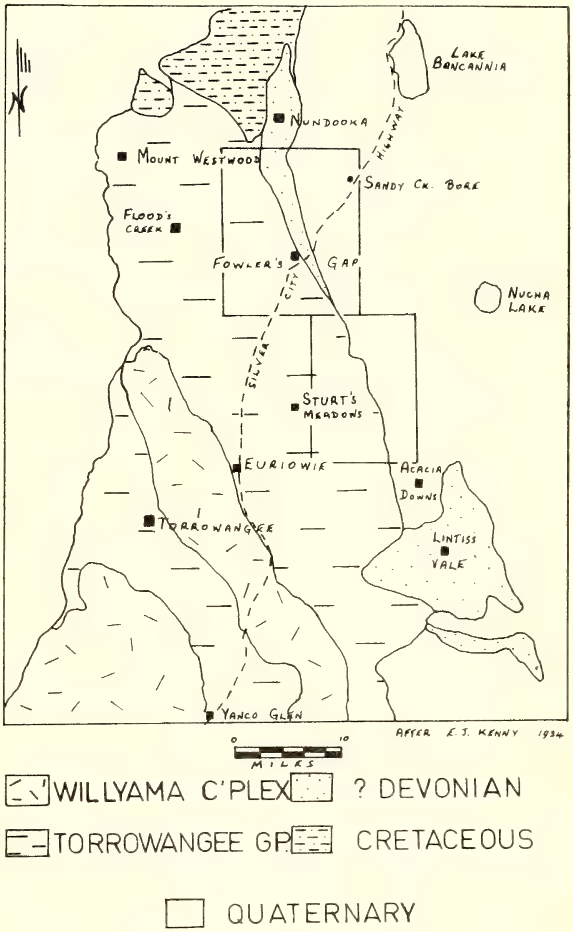

Fig. 4.—Regional geology

Depositional Environment of the Devonian

The association of quartzose sandstones with red and green siltstones and shales is considered (Pettijohn, 1957; Krumbein and Sloss, 1963) to be indicative of stable tectonic conditions. This is supported by the maturity of the sandstones and the presence of cross-bedding. The fish plates suggest a freshwater deposition (G. Rose, pers. comm.).

All writers (Voisey, 1959; Packham, 1960; Conolly, 1962) agree that, at the commencement of the Upper Devonian time the west of N.S.W.

was occupied by a miogeosyncline (Voisey, 1959) or molasse sedimentation conditions. This was a distinct environmental change from the engeosyncline or flysch of the earlier Palaeozoic. Conolly (1962) envisages a sea retreating eastwards throughout the Upper Devonian.

The Devonian sediments in the Coco Range Beds and the Nundooka Sandstone exposed to the north and east of Fowler's Gap probably represent the western limit of Upper Devonian sedimentation in the Lachlan Geosyncline. They rest unconformably on the quartzites and slates of the Proterozoic Torrowangee Group. The sandstones contain fragments of the underlying Torrowangee shale, suggesting that they were derived from the craton of the Broken Hill Block described by Packham (1960). However the lack of continuous outcrop between this area and the Mulga Downs Group (Conolly, 1962) at Cobar means that the stratigraphic position of these marginal sediments with respect to the remainder of the Upper Devonian sequence in N.S.W. is uncertain.

? Lower Tertiary

In the north-west of the area mapped several silcrete capped mesas occur. These consist of approximately 200 feet of sediment, the lower half being siltstone whilst the upper section is a sandstone or granule conglomerate. Further occurrences are substantially covered by colluvium around Sandstone Tank but isolated exposures are seen in creek beds.

Both the siltstone and the sandstone are very friable, although partially lithified. They are made up of quartz with a high proportion of muscovite flakes. The granule conglomerate is usually poorly sorted. A certain amount of calcareous cement is present.

The Lower Tertiary age assigned to these sediment is tentative only. They are older than the widespread " duricrust " or silcrete of western N.S.W. which is considered to be late Tertiary in age. (Kenny, 1934), and are believed to be younger than the Cretaceous sediments of the Great Artesian Basin (R. L. Brunker, pers. comm.).

? Tertiary

The duricrust of western N.S.W. has been studied by several authors including Woolnough (1927), Langford-Smith and Dury (1965) and Dury (1966). In the area mapped there are several outcrops of silcrete left as residuals by the present pattern of erosion. This silcrete is typically grey in colour and contains grains of quartz set in a cement of microcrystalline silica. Some phases with less prominent quartz grains contain plant fossils of the *Cinnamonum* flora. Pebbles, mainly of locally derived quartzite, are occasionally to be found, cemented together by fine grained silica as part of a silcrete outcrop.

The silcrete rests on all the above mentioned rock types including Proterozoic shales and quartzites, Devonian sandstones and the (?) Tertiary sediments described above. The outcrop east of Fowler's Gap Tank has been noted by Langford-Smith and Dury (1965) and one south-east of Tarnuna Tank (beyond the area mapped) at Acacia Downs is recorded by Dury (1966). The other occurrences mapped have not previously been recorded.

Ferricreted aggregates of rock fragments are occasionally exposed. Red-brown iron oxide material also becomes quite prominent on bedrock, especially the Devonian sandstones, and the profile resembles that of a laterite. It is younger than the silcrete since fragments of " grey billy " are included in the iron cemented aggregates.

Calcareous material, or " kunkar " is sometimes seen cementing rock fragments in creek beds. It also forms a coating several millimetres thick in the base of the dry channel. This is a white, powdery deposit, often with a pinkish coloration, composed essentially of calcium carbonate. It is much younger than the silcrete or ferricrete and appears to be a precipitate from the present day stream water.

Quaternary

In the eastern part of the area and extending for some 20 miles to the Mootwingee district are flat plains of alluvium. A thickness of greater than 300 feet is indicated in some bores. It is made up dominantly of clay the colour of which ranges from black and red-brown to white, with occasional thin sandy units. On the surface is a thin veneer of drift sand and pebbles with underlying red-brown silt and clay. Near the hills on the western margin of the plains deposits of talus are common, containing coarse pebbles of the nearby bedrock including vein quartz, and silcrete fragments. The veneer of sand is commonly shifted by wind action and shows ripple marks often two to three inches high. Sand dunes are sometimes developed.

A large area of talus is seen around Sandstone Tank in the north of the area. This is derived from the quartzite bedrock of the nearby hills set in a silty and clayey matrix of weathered shale. This deposit is being eroded by the present stream pattern rather than being built up, suggesting a recent vertical uplift, tilting down to the east, or possibly a change in the stream pattern due to river capture.

Acknowledgements

The authors would like to express their gratitude to many members of staff of the University of N.S.W. both in Sydney and Broken Hill for assistance during the field mapping, especially Prof. L. J. Lawrence, who acted as supervisor, and Mr. R. L. Mercer, manager of the Fowler's Gap Research Station. Officers of the Geological Survey, N.S.W. Dept. of Mines, especially Messrs. G. Rose and R. Brunker, who also gave invaluable help, as did Dr. M. J. Rickard of the Australian National University. Prof. J. J. Frankel, Mr. J. H. Bryan and Mr. G. Rose kindly read the manuscript and offered much useful criticism.

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Where Are the Electrons ?*

R. D. Brown

When chemists come to interpret their observations in terms of the atomic molecular theory of matter one of the first questions to be settled is : where are the electrons ? This may arise at a relatively elementary level in balancing a redox equation or using the octet rule to derive a structural formula. At more sophisticated levels of valency theory the interpretation of virtually all chemical and physical properties of compounds depends heavily on a knowledge of how the electrons are distributed over a molecule.

This knowledge of the distribution of electrons being so basic to chemistry, it is instructive to consider how profound is this knowledge. There is much to suggest that chemists are fairly well informed on this matter. For example, many papers in the current literature contain confident pictures of electron distributions in molecules (as portrayed by drawing in covalent bonds, charges on atoms, etc.) and of electronic shifts accompanying chemical reactions. Basic textbooks describe ionic and covalent bonds, and more advanced texts discuss bonds in transition element compounds with synergic back donation of π-electrons strengthening the metal ligand σ-bond and simultaneously ameliorating its polarity. What is rarely pointed out is that all of these descriptions of electron distributions are based upon sets of rather sweeping assumptions, the validity of which is open to question. Indeed, when looked into closely it is surprising how little we know beyond reasonable doubt about where the electrons are in molecules. I propose to try to illustrate the current fight with ignorance and to do it at two levels. Firstly, I want to consider how much we know about the gross distribution of electrons when we merely try to assess the net charges that should be associated with each atom. Secondly, I want to consider to what extent we can distribute the atomic electron densities among the different atomic orbitals associated with each atomic nucleus. Thus at the first level I shall consider the overall distribution of electrons in formaldehyde and other molecules. At the second level I shall touch on questions such as : are the 3d orbitals of sulphur used to any appreciable extent to accommodate valence electrons in SF_6 ? Let us start with the problem of gross charges.

If we are interested in the charge distribution in formaldehyde, for example, a textbook is likely to indicate the electronic structure as shown in Fig. 1. We should first ask what this means. The only aspect of charge distribution that is observable in principle is the total electron density at various points in space, $|\psi^2|$; in practice only certain derived quantities that I shall mention later have been observed.

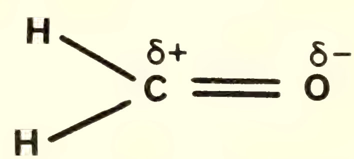


Fig. 1—Typical textbook representation of the charge distribution in formaldehyde.

Very accurate, theoretical information is available for some diatomic hydrides (Bader *et al.*, 1967), as shown in Fig. 2. To gain some impression of the changes that accompany bonding, it is useful to inspect the differences between these charge distributions and those for the separate uncharged atoms. Fig. 3 shows the difference maps. Fig. 4 shows an analysis into integrated charge transferred to bonding and to lone pair regions. We note that these data parallel our classical views that LiH is mainly ionic and that bonding becomes more and more covalent as we proceed across the periodic table. However, the appearance of the opposite ionic character, e.g. in HF, is hard to discern. One does not know just how this would reveal itself in the charge density contour maps—HF looks like the fluoride ion with a " pimple " representing the hydrogen.

* Liversidge Lecture delivered before the Royal Society of New South Wales, July 17th, 1968.

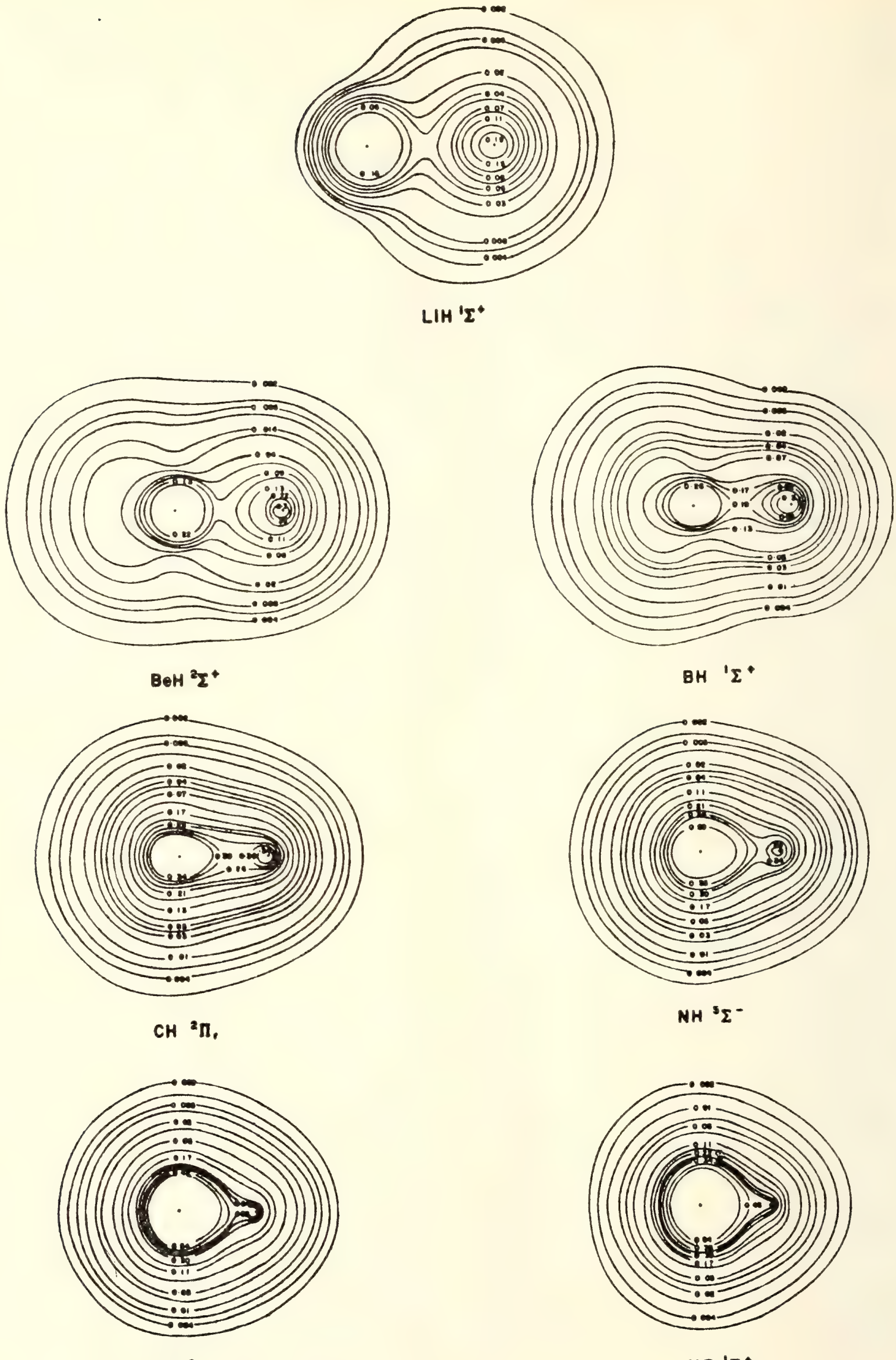


FIG. 2—Total molecular charge density contours for the first-row diatomic hydrides (atomic units ; H nucleus is on the right in each case). The innermost contours encircling the heavy nucleus have been omitted for the sake of clarity.

(Reproduced, with permission, from Bader *et al.*, 1967.)

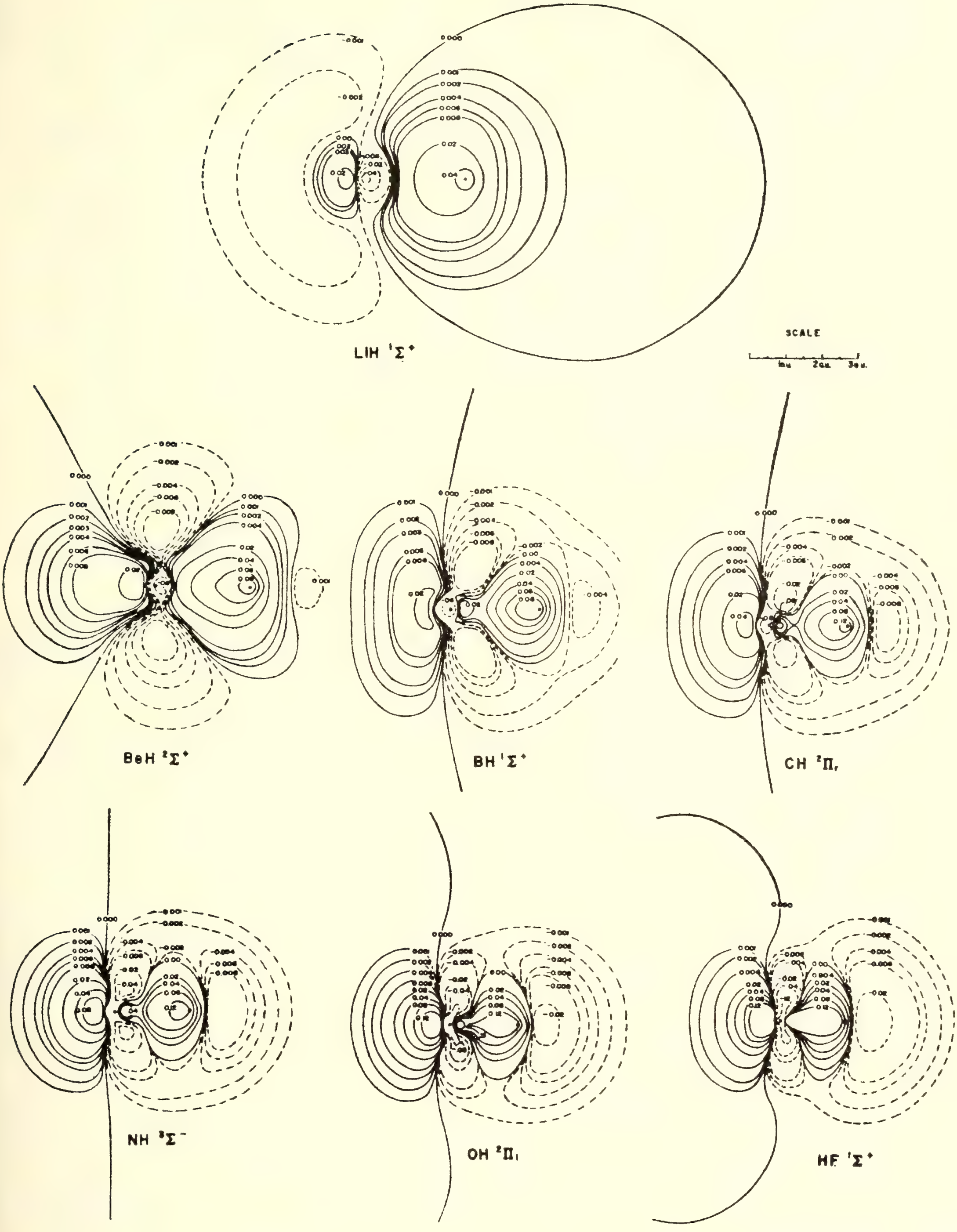


FIG. 3—Contour maps of the electron density difference (molecule—separate atoms) in atomic units for the first-row diatomic hydrides (H on right in each case).

(Reproduced, with permission, from Bader *et al.*, 1967.)

In order to associate different portions of the integrated charge density with different atoms, we must have some agreed scheme of partitioning. One could perhaps imagine surfaces dividing up all space into regions and associating each region with one of the atoms, but this presents difficulties in deciding where to place the partitions. However, instead it has proved more convenient to construct approximations of ψ using sets of functions associated with each of the atoms. We have become accustomed to call these functions atomic orbitals. It is straightforward to dissect the approximate $|\psi^2|$ algebraically in a way that yields occupation numbers for each of the atomic orbitals, and if we add up the occupation numbers for all of the orbitals on a particular nucleus we obtain the electron density for that atom. I do not want to go into details about this analysis, but rather to make two points.

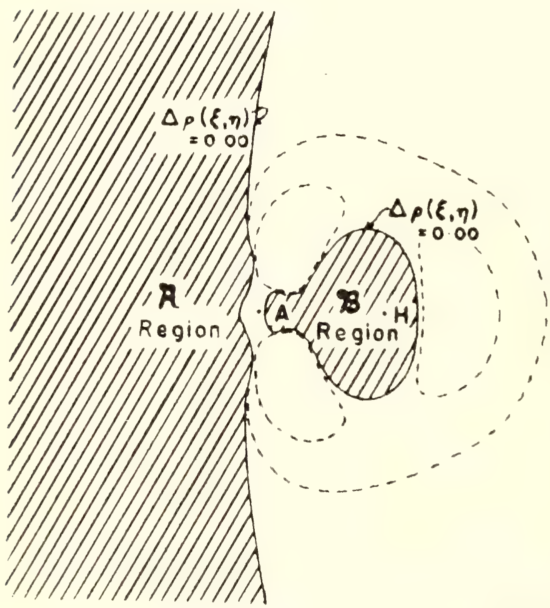


FIG. 4—Definitions of A and B regions.

Firstly, there is wide freedom in choosing the sets of atomic orbital functions used to represent ψ and it is even permissible to go to the extreme of using functions centred on only one of the atomic nuclei. In the latter case one might deduce that all the electrons are on one atom ! The lesson to be learned is that the conclusion that we draw about electron distributions will depend to some extent on the kind of atomic orbitals that we decide to use to build up the molecular eigenfunction. Secondly, if we use only a relatively simple set of atomic orbitals to obtain an approximate ψ the resultant analysis of electron distribution will be affected to some extent because we have not analysed the exact wave function.

*Total Charge Migration in Diatomic Hydrides as Determined by Density Difference Maps**

AH	Charge Increase in Region A	Charge Increase in Region B
LiH ..	0·01	0·55
BeH ..	0·11	0·35
BH ..	0·20	0·16
CH ..	0·20	0·16
NH ..	0·20	0·16
OH ..	0·22	0·19
HF ..	0·24	0·22

* These figures were obtained by numerical integration using a grid of 0·02 a.u. Regions A and B are defined in Figure above.

Reproduced from *J. Chem. Phys.*, 1967, **47**, 3381, Fig. 2 (6) and Table 11.

Let me now give you a survey of what some of the best available current wavefunctions for various small molecules have to say about charge distributions as analysed in terms of molecular orbitals, so that you can compare these with the popular mythology of textbooks. While I am doing this you may be asking how reliable are these wavefunctions, and later in this talk I shall point out some experimental data that can be used to test these wavefunctions.

First let us look at formaldehyde. The calculated electron distribution (Peters, **1963** ; Cook and McWeeny, 1968) is shown in Fig. 5. Notice that the qualitative tends to not agree with popular belief as represented in textbooks because the total carbon charge (—0·14) is more negative than the oxygen charge (—0·12). The overall polarity must be largely laid at the door of the positive net charges on the hydrogens, with an additional contribution from the atomic dipole of the oxygen. The carbonyl polarity is not that normally believed. It is possible that this is an artifact of the particular wavefunction used here, but several other recent approximate wavefunctions for formaldehyde display the same qualitative result.

As a second example (Veillard *et al.*, 1967), let us consider the prototype of the so-called dative bond $BH_3 \leftarrow NH_3$ (Fig. 6). From com-

parison with analogous calculations on BH_3 and on NH_3 separately, we see an interesting electron drift accompanying the association of the parts, quite different to that deduced by octet rule methods. In particular, the net charge on the boron is virtually unchanged by bond formation and a rather curious alternating drift of electrons, involving the hydrogens attached to boron, has occurred.

Somewhat similar distributions of electrons have been found in other saturated systems (Pople and Gordon, 1967). Thus when a fluorine substituent is introduced into a saturated hydrocarbon (Fig. 7) the immediate effect is to generate a net positive charge on the attached carbon, but the more distant influences seem to

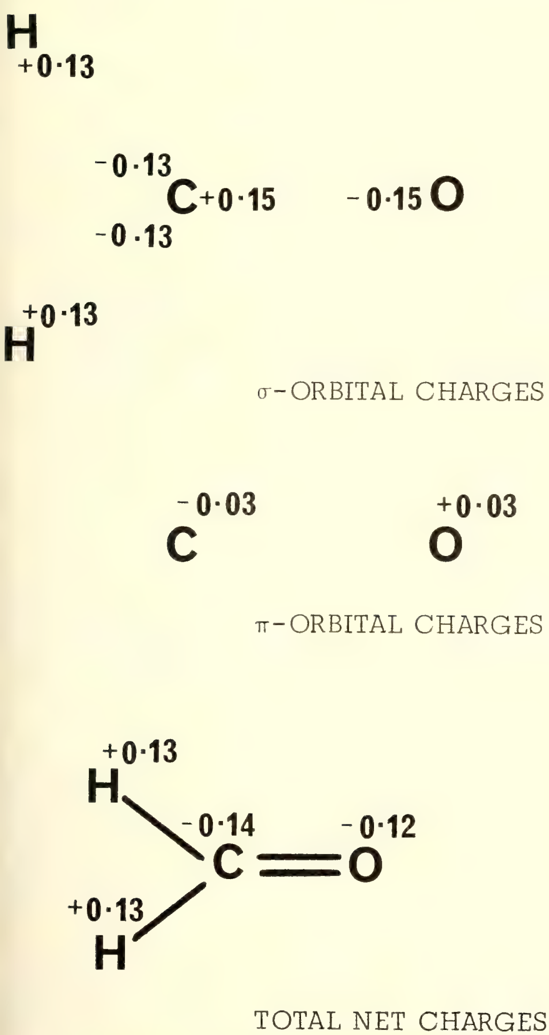


Fig. 5—Charge distribution in formaldehyde (Peters, 1963).

alternate in sign, not to fall monotonically! It is possible that a new set of rules for σ-electrons drifts will be called for in place of the beloved inductive shifts of organic chemistry.

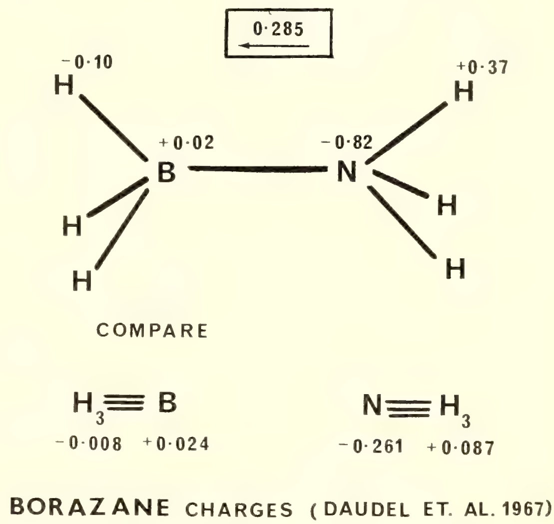
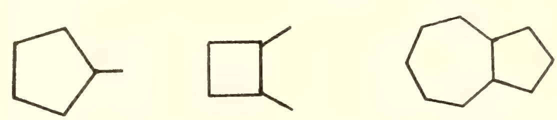


Fig. 6—Charge distribution in borazane (Daudel *et al.*, 1967).

Let me now turn to another example that has been of particular interest to us at Monash: that of non-alternant hydrocarbons. The interest centres largely around three conjugated cyclic hydrocarbons: fulvene (1), dimethylenecyclobutene (2) and azulene (3):



(1) (2) (3)

$\underbrace{\qquad\qquad}_{C_6H_6}$ $C_{10}H_8$

All three hydrocarbons have a substantial dipole moment—of the order of ten times the magnitude of analogous aromatic hydrocarbons. We ask to what should the polarity be attributed.

The initial proposal was that for conjugated hydrocarbons containing odd membered rings—so-called non-alternants—the distribution of π-electrons is non-uniform (Coulson and Rushbrooke, 1940), and this leads to the appreciable polarity. More recently it has been predicted (Brown and Burden, 1966), and then confirmed experimentally (Brown *et al.*, 1967), that dimethylenecyclobutene, though an alternant,

should have an uneven distribution of π-electrons and so be polar. In attempting to account in more detail for the polarity, it has been suggested that the σ-electrons also contribute to the polarity, particularly because the hydrogen atoms are appreciably charged. Let us see now what the best available wave functions imply, first with dimethylenecyclobutene (Fig. 8).

Here the implication is that the polarity must be ascribed primarily to π-electrons, the total σ-electron effect being a minor contribution. The agreement of the calculated value with the observed dipole moment is impressive. However, let us next turn to fulvene (Fig. 9). Here the qualitative story is similar to that of dimethylenecyclobutene, but the agreement with the experimental dipole moment data is less satisfactory. Hitherto the value, deduced from measurements in solution on substituted fulvene, was 1·1D. We have been engaged in a precision measurement on fulvene vapour by microwave methods and now find that the dipole moment is 0·44D.

In the case of azulene, the story is still less satisfying. The theoretical computations again imply that the polarity stems essentially from a non-uniform π-electron distribution (Fig. 10) but the theoretical value of the moment is depressingly far from a recent precise experimental value for azulene vapour (Tobler *et al.*, 1965). Thus it is clear that the presently available electronic wavefunctions for molecules like azulene are not all that we would like; but perhaps the qualitative indication of the relative polarity contributions from σ- and π-electrons are sound.

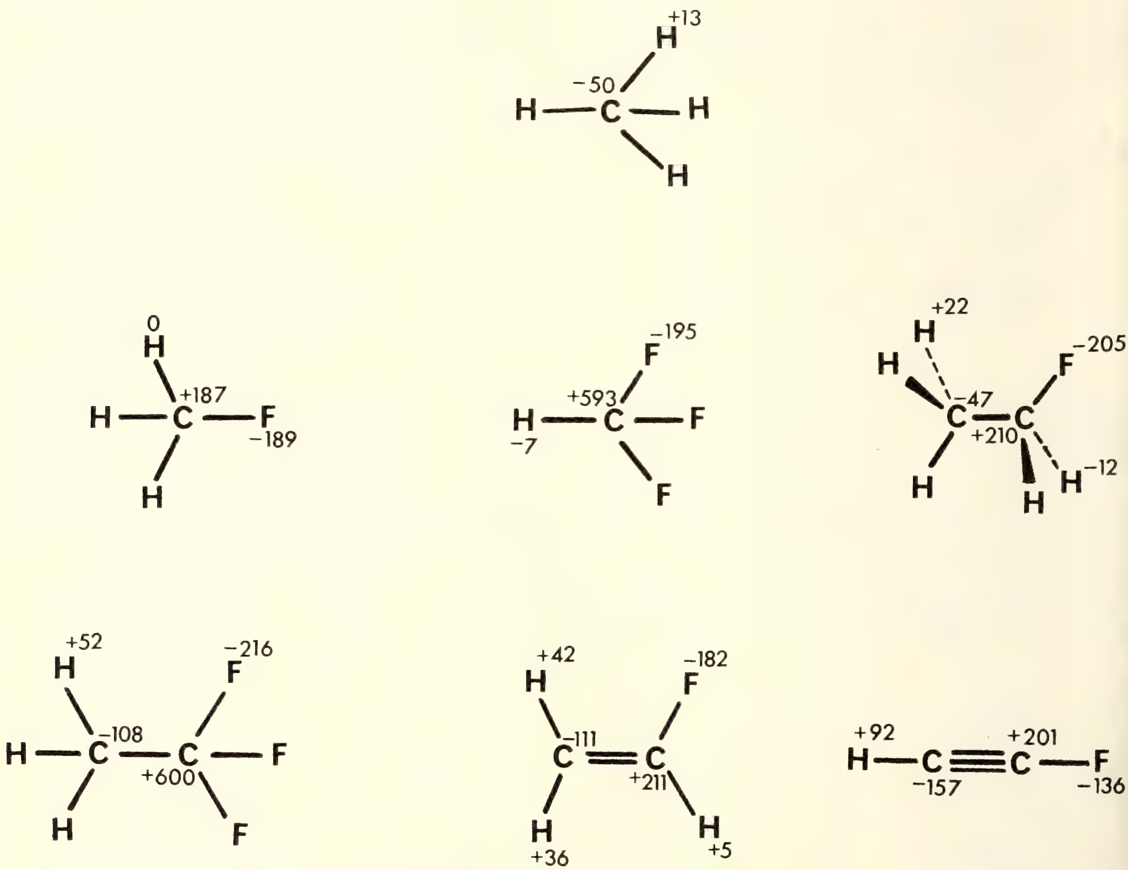
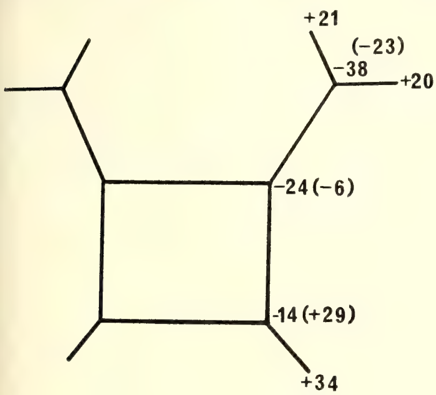


FIG. 7—Charge distribution in fluorocarbons (milliprotonic units).

Now let us move on to somewhat more complex systems involving larger atoms. First, a few words about SF_6, PF_5, etc. Textbooks will sometimes describe the bonding as involving sp^3d^2 or sp^3d hybrids on the central atom

these hybrids being used to form somewhat polar covalent bonds with the fluorine ligands. Alternatively, a structure involving ionic-covalent resonance among the various ligand positions and only the s and p orbitals on the S (or P), has sometimes been advocated. On close analysis, it proves difficult to decide whether the d-orbitals of the central atom are involved in the bonding because of the variety of functional forms that can be written down



DIMETHYLENE CYCLOBUTENE net charges (e/1000)
π net charges in parentheses

Dipole moment

σ densities	0.254 D	↑
σ hybridization	0.231	↓
π densities	0.607	↓
TOTAL	0.584 D	↓
experiment:	0.61_8 D	

FIG. 8—Dimethylenecyclobutene.

as representing a d-orbital. However, if we agree that by orbitals we mean the various functions that are obtained by solving the H-atom problem so that

$$f_{3d}=N.\rho^2e^{-\rho/3}.Y_{2m}(\theta,\varphi) \quad (\rho=\zeta r/a)$$

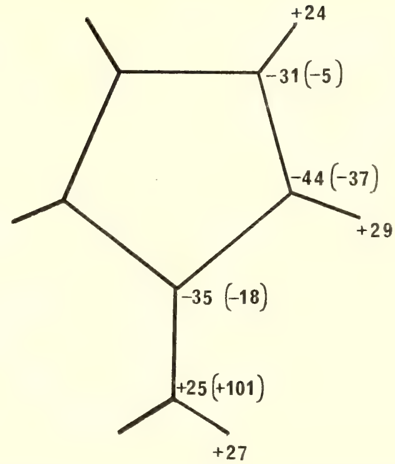
(Y_{2m}: spherical harmonic of order 2)

then the best function that has so far been derived for these molecules (by Dr. Peel) implies (Table 1) that the 3d orbitals are insignificantly occupied in SF_6, PF_5, SF_4, ClF_5, etc.

TABLE 1

Orbital Occupation Numbers

	PF_5	SF_4	ClF_3
3s ..	1·09	1·53	1·75
3p ..	2·15	2·67	3·80
3d ..	0·13	0·22	0·19



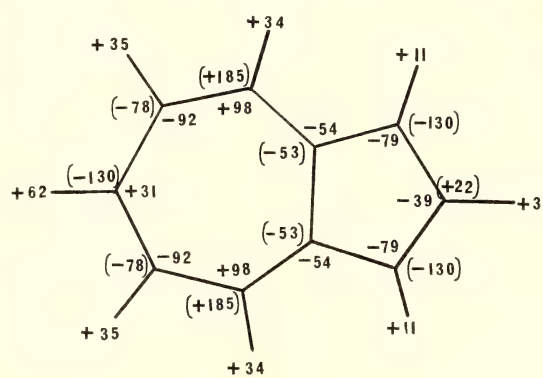
FULVENE net charges (e/1000)
π net charges in parentheses

Dipole Moment

σ densities	0.260 D	↑
σ hybridization	0.086	↓
π densities	1.061	↓
TOTAL	0.887 D	↓
experiment:	0 44 D	

FIG. 9—Fulvene.

Another example involving a transition element atom is the electronic structure of the permanganate ion. In recent years a number of investigations of the electronic structure of tetrahedral anions have been published. The



AZULENE NET CHARGES (e/1000)
π net charges in parentheses

Dipole Moment

σ density	0.809 D	→
σ hybridization	0.589	←
σ total	0.220	→
π density	3.446	←
TOTAL	3.226 D	←
experiment	0.79_6 D	

FIG. 10—Azulene.

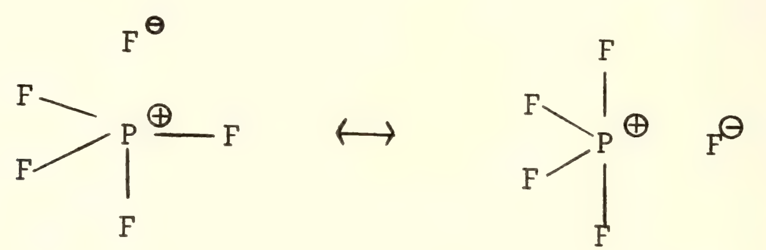
most elaborate of these (Table 2), obtained by Mr. James at Monash, implies that the 4s and 4p orbitals of Mn are but little occupied, the central atom using its 3d orbitals almost exclusively to accommodate valence electrons.

TABLE 2

Orbital Occupation Numbers

	MnO_4^-		CrO_4^{--}	
	MCZDO	CNDO	MCZDO	CNDO
3d	5·70	6·71	5·84	6·56
4s	0·08	0·10	0·04	0·10
4p	0·00	0·02	0·00	0·15

These calculations on systems containing larger atoms are necessarily rather less rigorous than those on smaller systems and it is possible that the picture could be changed somewhat by still more elaborate calculations. However, it seems unlikely that the qualitative description will be noticeably altered. The overall picture that we are left with is one rather different from the classical description in current textbooks.



Returning now to smaller systems, let us consider what kind of experimental tests can usefully be applied to molecular wavefunctions. Because of the widespread use of the variation theorem for computing wavefunctions, a habit of mind has grown of asking what kind of energy expectation value derives from the function ψ.

$$\langle E\rangle=\langle\psi\,|\,\hat{\mathscr{H}}\,|\,\psi\rangle/\langle\psi\,|\,\psi\rangle$$

The more negative $\langle E\rangle$ is the better function ψ is considered to be. However, the energy test depends critically on how well ψ accounts for electron correlation. If we are interested in electron distribution this correlation effect is less important and so functions that give only moderate values of $\langle E\rangle$ can sometimes give a good picture of the overall electron distribution in the molecule. It therefore seems better to apply different tests, namely the following:

$\langle r\rangle=\langle\psi\,|\,\hat{r}\,|\,\psi\rangle/\langle\psi\,|\,\psi\rangle$ derived from dipole moment.

$\langle r^2\rangle$—relative to molecular centre of gravity—derived from molecular g factor and susceptibility.

$\langle 1/r\rangle$—relative to a nucleus with $I\neq 0$—derived from spin rotation constant and chemical shift for a nucleus of non-zero spin.

Etc.

Most of these quantities are particularly taxing to determine experimentally, but values are starting to emerge for a few simple molecules as a result of the efforts of Flygare and his co-workers at Illinois. Values that he has just published for formaldehyde (Hüttner *et al.*, 1968) are shown in Tables 3 and 4. These

TABLE 3

Experimental Mean Values for Electrons in Formaldehyde

$\langle x^2\rangle$ ..	$3{\cdot}2\pm0{\cdot}3\times10^{-16}$ cm.^{2}
$\langle y^2\rangle$ ..	$5{\cdot}2\pm0{\cdot}3\times10^{-16}$ cm.^{2}
$\langle z^2\rangle$ ..	$11{\cdot}4\pm0{\cdot}3\times10^{-16}$ cm.^{2}

TABLE 4

Experimental Values (A.U.) of Various Electronic Properties of Formaldehyde

$q_{zz}(O)$	$-0{\cdot}703$
$q_{yy}(O)$	$-1{\cdot}687$
$r_0\cos\theta$	19·495
x^2	11·3
y^2	18·7
z^2	40·8
$z_O/r^3{}_O$	1·261
$z_C/r^3{}_C$	1·262
$q_{\alpha\alpha}(D)$	$-1{\cdot}446$
$q_{\alpha\beta}(D)$	$-0{\cdot}178$
$q_{\beta\beta}(D)$	0·650
$\alpha_D/r^3{}_D$	2·059
$\beta_D/r^3{}_D$	0·266
$1/r_H$	6·12

provide a very stringent test of electronic wavefunctions and so far even the best published wavefunctions for formaldehyde show deficiencies. However, further experimental work of this kind and further computational effort on wavefunctions must surely produce a steady increase in our knowledge of how the electrons are distributed in molecules.

Maybe if you are kind enough to invite me again to Sydney some years hence to talk on " Where Are the Electrons ? " I may be able to give you more confident answers such as textbooks now give. At present the honest answer is : " We do not know for sure but we have some suspicions ! "

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(Delivered on 17 July 1968)

Let R be the total resistance of the intake, so that r is the resistance per unit length and $R=rL$. If g is the conductance of the barrier per unit length of airway, then the total conductance of the barrier is $G=gL$. (Conductance is the inverse of resistance).

In this model we have not only neglected the irregularities of the mine but also the change of air density due to pressure and temperature. The effect of pressure changes is not very important, but temperature changes are large and could be important.

3. Simple Solution of the Model

Now we have a model and can begin to attempt a mathematical solution.

If the quantity of air entering the mine per second is Q_0 and the quantity reaching the face is Q_F, then Q_0-Q_F is lost through the goaf and $\frac{Q_0+Q_F}{2}$ is the average quantity flowing through the airways. Working with averages, the equation for flow in the airways is:

$$P_0=R\left(\frac{Q_0+Q_F}{2}\right)^2$$

and since the average pressure difference between the airways is P_0, the flow through the goaf is given by

$$(Q_0-Q_F)=GP_0.$$

If instead of turbulent flow in the airways we assumed streamlined flow so that

$$P_0=R\left(\frac{Q_0+Q_F}{2}\right)$$

then

$$P_0^2=\frac{R}{2G}\,(Q_0^2-Q_F^2)$$

and

$$Q_0/Q_F=1+RG.$$

4. A More Sophisticated Solution

The use of averages is not the approach of the applied mathematician. He will set up the equations in terms of the differential calculus, which gives

$$\frac{dP}{dl}=rQ^2$$

$$\frac{dQ}{dl}=2gP$$

for flow through minute lengths of airway and minute widths of barrier, remembering that the pressure difference between the airways is $2P$.

The solution of these equations gives relations between the pressure and quantity of air at any point of the airways (Peascod and Keane, 1955; Keane, 1956). Since $rL=R$ and $gL=G$, we find that

$$P^2=\tfrac{1}{3}\,\frac{R}{G}\,(Q^3-Q_F^3)$$

and

$$\frac{RG}{3}Q_F=\left\{F\left(\frac{1}{2},\frac{1}{6};\frac{7}{6};1\right)-k^{\frac{1}{2}}F\left(\frac{1}{2},\frac{1}{6};\frac{7}{6};k^3\right)\right\}^2$$

where

$$k=Q_F/Q_0,$$

and F is the hypergeometric function.

If the flow in the airways were assumed streamlined, then the equations would reduce to

$$\frac{dP}{dl}=rQ \quad\text{and}\quad \frac{dQ}{dl}=2gP,$$

which gives the solutions

$$P^2=\frac{R}{2G}(Q^2-Q_F^2)$$

and

$$Q_0=Q_F\cosh 2\sqrt{RG}.$$

These equations show that the use of averages in the previous section underestimates the leakage loss.

5. Improvements to the Model

We should now look closer at the assumptions of our model to see if it can be improved. The square law holds for fully turbulent flow, while the linear law holds for streamlined flow. In the airways it seems reasonable to assume that the flow lies somewhere between these two limits and a more realistic equation would be $P=RQ^n$ where $1\leqslant n\leqslant 2$ (Groden, 1956).

Measurements of pressure and air flow in a mine in the Newcastle district showed that the value of n should be $1{\cdot}85$. This practical study combined with improved computational techniques, formed the content of a Ph.D. thesis and was published in part by the Institute of Mining and Metallurgy (Rose, 1958).

It is usual practice in a mine to keep the intakes in good repair for the transport of men and materials and to let the returns fall into disrepair. This means that the resistances of the intake and return are not equal. If we still retain the assumption that the resistance of an airway is uniform, we can allow for the difference between the intake and return by using the average resistance of the airways (Low, 1956).

Up to this stage our model has assumed that the air leaking through the goaf travels in a direction at right angles to the airways. This in turn means that there is no pressure drop in the goaf in the direction of the airways—which is clearly wrong unless the goaf is impervious in this direction.

Referring to Figure 2, and assuming that flow of air is symmetrical about the x-axis, we can

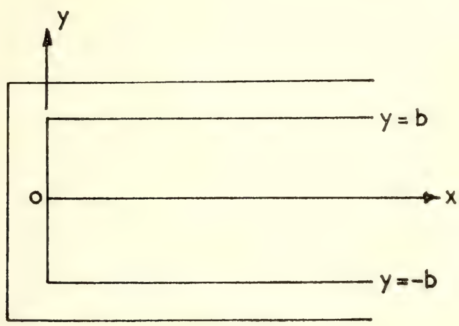

FIG. 2

allow for some air motion in the direction of the airways by taking the pressure in the goaf to satisfy the equation

$$\frac{\partial^2 p}{\partial y^2}+\lambda^2\frac{\partial^2 p}{\partial x^2}=0. \quad \ldots\ldots\ldots\ldots \quad (1)$$

If $\lambda=0$, we return to the previous model, while with $\lambda=1$ there is no preferable direction of motion. The value of λ depends on the particular method of mining.

The mathematical problem now is to solve the partial differential equation (1) subject to the boundary conditions

$$P=(p)_{y=b}$$

$$\frac{\mathrm{d}Q}{\mathrm{d}x}=\left(k\frac{\partial p}{\partial y}\right)_{y=b} \quad \ldots\ldots\ldots\ldots \quad (2)$$

$$\frac{\mathrm{d}P}{\mathrm{d}x}=rQ^n.$$

where $2b$ is the thickness of the goaf and $k=2bg$.

6. Solution for Streamlined Flow

When $n=1$ so that $\frac{\mathrm{d}P}{\mathrm{d}x}=rQ$ in the boundary conditions, corresponding to streamlined flow in the airways, there are known techniques for solving the partial differential equation.

Separation of variables leads to the solution as a sum of eigen solutions in the form

$$P(x,y)=\Sigma\frac{\sin\lambda y m_n}{\lambda m_n}A_n\sinh m_n x$$

where m_n are the roots of the equation

$$m\sin\lambda bm=\lambda rk\cos\lambda bm.$$

As an added boundary condition we will assume that no air leaks into the goaf between the mine entrances, so that

$$\frac{\partial p}{\partial y}=P_0/b$$

when $x=L$.

As a special case of the Dini expansion (Watson, 1944, p. 576), we can expand this boundary condition to determine the A_n, and thence the solutions

$$P=\frac{P_0}{b}\Sigma\frac{2rk}{b\lambda^2 rk+\sin^2\lambda bm_n}\,\frac{\sin^2\lambda bm_n}{m_n^2}\,\frac{\sinh m_n x}{\sinh m_n L}$$

$$Q_0=\frac{P_0}{b}\Sigma\frac{2k}{b\lambda^2 rk+\sin^2\lambda bm_n}\,\frac{\sin^2\lambda bm_n}{m_n}\coth m_n L$$

$$Q_F=\frac{P_0}{b}\Sigma\frac{2k}{b\lambda^2 rk+\sin^2\lambda bm_n}\,\frac{\sin\lambda bm_n}{m_n}\operatorname{cosech} m_n L$$

7. A General Approximate Solution

For general values of n, a numerical approach will be required to obtain an accurate result. The errors introduced by numerical approximation can be reduced to a suitable level by comparison with the exact solution for $n=1$.

To proceed analytically, we have chosen to use operational techniques, but the approximations that have to be introduced require very careful study to establish their validity.

Writing equation (1) in operational form,

$$\frac{\partial^2 p}{\partial y^2}+\lambda^2 D^2 p=0,$$

where $D=\frac{\partial}{\partial x}$.

Subject to the condition $p=0$, $y=0$, we obtain

$$p=\frac{\sin\lambda yD}{\lambda D}B(x)$$

or on applying the boundary conditions (2)

$$\frac{\mathrm{d}Q}{\mathrm{d}x}=k\lambda D\cot\lambda bD.P$$

$$=2g\lambda bD\cot\lambda bD.P.$$

University of Western Australia, Wollongong University College.

Companies—A.C.I. Ltd., Aust. Iron & Steel Co. Ltd., A.W.A. Ltd., B.H.P. Co. Ltd., Blue Metal & Gravel Co., Commonwealth Steel Co., C.S.R. Co. Ltd., Head Office ; Davis Gelatine Co., International Engineering, J. Lysaght Ltd., Mt. Isa Mines Ltd., Qantas, Standard Telephones & Cables, Unilever Ltd., Union Carbide Ltd.

Research Institutes—Animal Research Institute, Queensland ; B.H.P. Co. Ltd., Research Laboratories, Shortland ; Bread Research Institute ; C.S.R. Co. Ltd., Research Laboratory ; I.C.I. Research ; Institute of Dental Research ; Royal North Shore Hospital ; Government Chemical Laboratories, Perth ; Chemical Division, D.S.I.R., New Zealand.

Museums—Adelaide Museum ; Australian Museum ; Geological Museum and Library, Melbourne ; New Zealand Institute and Museum.

Miscellaneous—Encyclopedia Britannica ; Institution of Engineers, Aust., Dept. of Primary Industries, Brisbane.

J. L. GRIFFITH.

Hon. Secretary.

3rd April, 1968.

The Honorary Treasurer's Report

The Society this year recorded a deficit of $480.23, as against $2,133.00 for the year 1966–67. Expenditure dropped by $1,018.00, and income showed an increase of $658.00. The drop in expenditure was mainly due to a decrease of $881.00 in the cost of the Journal and to the additional expenditure in 1966–67 of $402.00 on the centenary celebrations. The increase in surplus from the Science House Management Committee accounted for the increase in income.

The Science House Management Committee increased the rents of all tenants as from 1st June, 1967. As a result, the Society's rent for the year increased by $528.00 and its share of the Science House surplus by $661.00.

H. F. CONAGHAN,
Honorary Treasurer.

Abstract of Proceedings

5th April, 1967

The one hundredth Annual and eight hundred and seventeenth General Monthly Meeting was held in the Hall of Science House, 157 Gloucester Street, Sydney, at 7.45 p.m.

The President, Professor A. H. Voisey, was in the chair. There were present 52 members and visitors.

Reginald William Hodgins, Konrad Heinrich Richard Moelle and Bevan Jon Warris were elected members of the Society.

The Annual Report of the Council and the Financial Statement were presented and adopted.

The following awards of the Society were announced :

The Society's Medal for 1966 to Mr. H. A. J. Donegan, M.Sc.

The Clarke Medal for 1967 to Professor S. Smith-White, D.Sc.Agr., F.A.A.

The James Cook Medal for 1966 to Sir William Hudson, K.B.E., F.R.S.

The Edgeworth David Medal for 1966 to Dr. R. I. Tanner.

The Archibald D. Ollé Prize to Dr. R. A. Binns.

Notice of motion was given regarding proposed New Rules and By-Laws.

Office-bearers for 1967–68 were elected as follows :

President : A. H. Low, Ph.D.

Vice-Presidents : A. A. Day, Ph.D. (Cantab.), R. J. W. Le Fevre, D.Sc., F.R.S., F.A.A., W. H. G. Poggendorff, B.Sc.Agr., A. H. Voisey, D.Sc.

Hon. Secretaries : J. L. Griffith, B.A., M.Sc., A. Reichel, Ph.D., M.Sc.

Hon. Treasurer : H. F. Conaghan, M.Sc.

Members of Council : R. A. Burg, A.S.T.C., J. C. Cameron, M.Sc., B.Sc. (Edin.), D.I.C., R. J. Griffin, B.Sc., T. E. Kitamura, B.A., B.Sc.Agr., M. Krysko v. Tryst (Mrs.), B.Sc., Grad.Dip., D. B. Lindsay, B.Sc., M.A., D.Phil. (Oxon.), J. W. G. Neuhaus, M.Sc., J. P. Pollard, Dip.App.Chem. (Swinburne), M. J. Puttock, B.Sc.(Eng.), A.Inst.P., W. H. Robertson, B.Sc.

Messrs. Horley & Horley were re-elected Auditors to the Society for 1967–68.

The retiring President, Professor A. H. Voisey, delivered his Presidential Address, entitled " Geological Techniques ".

The following papers were read by title only :

" Petrology and Origin of the Cocoparra Group, Upper Devonian, New South Wales ", by J. R. Conolly.

" Autocondensation of Urea at 105–110° C.", by E. V. Lassak.

" Middle Devonian Conodonts from the Moore Creek Limestone, Northern New South Wales ", by G. M. Philip.

" Cyclic Sedimentation in the Carboniferous Continental Facies, New South Wales ", by J. H. Rattigan.

" A Note on Convex Contributions ", by J. L. Griffith.

At the conclusion of the Presidential Address the retiring President welcomed Dr. A. H. Low to the Presidential Chair.

3rd May, 1967

The eight hundred and eighteenth General Monthly Meeting was held in the Hall of Science House, 157 Gloucester Street, Sydney, at 7.45 p.m.

The President, Dr. A. H. Low, was in the chair. There were present 40 members and visitors.

Boyd Thomas Pratt, Lawrence Sherwin, Stanley Arthur South, Don Gregory Thompson and Philip Damien Tilley were elected members of the Society.

Motion. The Honorary Secretary moved that

" The Society adopt the New Rules and By-Laws as circulated to members together with the addition of By-Law 5 (*g*).

The ballot for the election of the Council shall take place at the Annual General Meeting. However, any member may make a postal vote if desired."

(This By-Law has been agreed to by Council but was inadvertently omitted from the typescript of the proposed By-Laws.)

A paper entitled " Cambro-Ordovician Sediments from the North-eastern Margin of the Frome Embayment (Mt. Arrowsmith, N.S.W.) ", by H. Wopfner, was read by title only.

Symposium. " The Problem of Transition from School to University Mathematics." The speakers were : Associate Professor W. B. Smith-White—" A Comparison of Schools and University Mathematics and of the Customary Methods in Teaching " ; Mr. J. L. Griffith—" Literary Content of Mathematics " ; Mr. M. G. Greening—" Some Attempts at Alleviating the Problem ".

7th June, 1967

The eight hundred and nineteenth General Monthly Meeting was held in the Hall of Science House, 157 Gloucester Street, Sydney, at 7.45 p.m.

The President, Associate Professor A. H. Low, was in the chair. There were present 36 members and visitors.

The motion regarding New Rules and By-Laws carried at the May General Monthly Meeting was confirmed. The motion read : " That the Society adopt the New Rules and By-Laws as circulated to members together with the addition of By-Law 5 (*g*). The ballot for the election of the Council shall take place at the Annual General Meeting. However, any member may make a postal vote if desired."

TRUST FUNDS

	Clarke Memorial $	Walter Burfitt Prize $	Liversidge Bequest $	Ollé Bequest $
Capital at 29th February, 1968	3,600.00	2,000.00	1,400.00	—
Revenue—				
Balance at 28th February, 1967 ..	670.32	426.43	25.04	581.26
Income for the Year	182.34	101.18	71.48	84.50
	852.66	527.61	96.52	665.76
Less : Expenditure	184.37	—	—	60.00
	$668.29	$527.61	$96.52	$605.76

ACCUMULATED FUNDS

	$	$
Balance at 28th February, 1967		57,870.28
Less :		
Increase in Reserve for Bad Debts ..	67.04	
Subscriptions Written Off	34.65	
Subscriptions Waived..	1.05	
Deficit for the Year	480.23	
		582.97
		$57,287.31

Auditors' Report

The above Balance Sheet has been prepared from the Books of Account, Accounts and Vouchers of the Royal Society of New South Wales, and is a correct statement of the position of the Society's affairs on 29th February, 1968, as disclosed thereby. We have satisfied ourselves that the Society's Commonwealth Bonds and Inscribed Stock are properly held and registered.

HORLEY & HORLEY,
Chartered Accountants.
Registered under the Public Accountants
Registration Act 1945, as amended.

65 York Street,
Sydney.
25th March, 1968.

(Signed) H F CONAGHAN,
Hon. Treasurer.
A. H. LOW,
President.

INCOME AND EXPENDITURE ACCOUNT

1st MARCH, 1967, TO 29th FEBRUARY, 1968

1967 $				$
35	Advertising			50.87
50	Annual Social			58.35
76	Audit			80.00
50	Branches of the Society			50.00
402	Centenary Celebrations			—
328	Cleaning			312.00
89	Depreciation			85.39
75	Electricity			72.34
10	Entertainment			17.70
75	Insurance			83.29
30	Legal Expenses			—
438	Library Purchases			295.31
450	Miscellaneous			448.78
318	Postages and Telegrams			298.92
	Printing—Journal—			
	Vol. 100, Parts 2–4	$2,796.61		
	Reprints	355.76		
	Postages	133.61		
			3,285.98	
	Less :			
	Sale of Reprints	725.28		
	Subscriptions to Journal	704.60		
	Sale of Back Numbers	34.50		
	Refund Postages	30.65		
			1,495.03	
2,671				1,790.95
24	Printing—General			188.59
2,454	Rent—Science House Management			2,982.75
15	Repairs			4.70
3,330	Salaries			3,094.18
87	Telephone			81.70
$11,007				$9,995.82

1967 $		$
1,949	Membership Subscriptions	1,972.65
13	Proportion of Life Members' Subscriptions	12.60
1,500	Government Subsidy	1,500.00
4,876	Science House Management—Share of Surplus	5,536.97
526	Interest on General Investments	489.67
10	Donations	3.70
2,133	Deficit for the Year	480.23
$11,007		$9,995.82

Obituaries

1967-1968

Lord Howard Walter Florey, who died on 22nd February, 1968, was born in Adelaide on 24th September, 1898. He was educated at St. Peter's College and at the University of Adelaide, and later at Oxford and Cambridge. He was Rhodes Scholar for South Australia, 1921 ; Rockefeller Travelling Fellow in the United States, 1925 ; Huddersfield Lecturer in Special Pathology, Cambridge, from 1927 ; Joseph Hunter Professor of Pathology, University of Sheffield, 1931–35; Professor of Pathology and Head of the Pathology School, Oxford, 1935–62; and Provost of Queen's College, Oxford, from 1962.

Lord Florey received many scientific and academic honours, both British and foreign. He was Nuffield Visiting Professor to Australia and New Zealand, 1944 ; the first Australian President of the Royal Society, 1960–65 ; Nobel Prize Winner for Physiology and Medicine, 1945 (shared with E. Chain and A. Fleming). In 1941 he was elected a Fellow of the Royal Society, Knighted in 1944, and created a Life Peer in 1965.

Florey's best known work was on penicillin ; its great therapeutic qualities remained unknown until experiments were conducted at Oxford by Florey and Chain.

During the Second World War he worked at Oxford with Keith Hancock, Mark Oliphant and Raymond Firth in formulating the concept of an Australian National University as a centre for post-graduate research. In 1944 he proposed the idea of the John Curtin School for Medical Research and was Chancellor of the University in 1965.

Lord Florey was elected an Honorary Member of the Society in 1949.

Edward William Esdaile, who died on 2nd October, 1967, was born in England on 26th November, 1882, and arrived in Australia in August, 1883, by sailing ship. He was educated at Fort Street School, and on leaving was apprenticed to the business of scientific and optical instrument makers which his father had established at 54 Hunter Street, Sydney, and he remained with the firm until his retirement in 1960.

Mr. Esdaile was a member of the British Astronomical Association, and took a great interest in designing and manufacturing telescopes and microscopes. He was well known at Sydney Observatory and later at the Belfield Amateur Astronomical Society.

He is survived by his widow and six of his seven children. Two of his sons now carry on the firm, which is situated at Glebe in larger premises.

Mr. Esdaile had been a member of the Society for many years, having been elected to membership in 1908.

Edward Gordon Haig Manchester was born on 2nd June, 1925, at Sydney, and was educated at The Hutchins School, Hobart, and Wesley, Melbourne. He graduated M.B., B.S., University of Sydney, in 1948.

Following graduation, Dr. Manchester was Junior Resident Medical Officer at Royal Prince Alfred Hospital, Sydney, until 1950, when he joined the R.A.A.M.C. He served as Medical Officer at B.C. of General Hospital, Japan, and in 1951 with the Field Ambulance Section, Korea. On his return to Australia he was O.C. 3 Camp Hospital.

In 1953 Dr. Manchester was Radiology Registrar, Royal Prince Alfred Hospital, Sydney, and in 1955 Assistant Radiologist, qualifying M.C.R.A. During 1956–58 he was an Assistant Radiologist in private practice, and was Honorary Radiologist at Crown Street, Western Suburbs and Sydney Hospitals. In 1959 he was Radiologist, Cerebral Surgery and Research Unit at Callan Park, and during 1960–62 was Director of Radiology, Launceston General Hospital, Tasmania.

Returning to Australia in 1963, Dr. Manchester was Medical Officer at the Australian Atomic Energy Commission, Lucas Heights, and from 1964 to the time of his death on 24th September, 1967, he was Assistant Director, Radiology Department, Sydney Hospital.

Dr. Manchester was elected to membership of the Society in 1965, and although his term of membership was a short one, he gave valuable assistance regarding assessments of the medical books in the library.

He is survived by Mrs. Rosemary Manchester and four small children.

Frank Richard Morrison, a member of the Society since 1922, died on 2nd October, 1967. He was a member of Council, 1942–1951, holding the position of Honorary Secretary, 1946 and 1947, and that of Vice-President, 1948, 1949 and 1951. Mr. Morrison was elected President in 1950 and in 1958 he was awarded the Society's Medal in recognition of his distinguished contributions to the science of chemistry and to services to the Society.

He received his scientific training at the Sydney Technical College, and joined the scientific staff of the Museum of Applied Arts and Sciences (then known as the Sydney Technological Museum) in 1916, entering the laboratory of H. G. Smith.

After his return from service abroad with the Australian Military Forces in the First World War, Mr. Morrison was joined in 1919 by Mr. A. R. Penfold, with whom he collaborated in their now famous researches on the chemistry of the Australian essential oil flora, continuing and expanding the labours of Baker and Smith. Thirty-four papers, either as sole author

or with Penfold as co-author, were published in the Society's " Journal and Proceedings ". Probably the most significant contribution in this work was the " physiological form " concept, which demonstrated the frequency with which plant species may exist in chemically divergent forms, morphological constancy being preserved. The discovery of these chemically variable species has led to a great interest in this problem, and many chemists, geneticists and taxonomists are still working out its implications.

His Presidential Address, entitled " The Science Museum—Its Duties and Its Dues ", indicated his interest in science museum administration, and in 1952 he represented the museums of Australia as a UNESCO Fellow at the International Seminar on " The Role of Museums in Education ", held in New York.

He held the post of Director of the Museum of Applied Arts and Sciences from 1956 until his retirement in 1960.

He is survived by Mrs. Beryl Morrison and an only child, the Reverend Alexander Morrison.

Patrick Desmond Fitzgerald Murray was born at Dorchester, England, on 18th June, 1900, and died on 17th May, 1967. He was educated at St. Ignatius' College (Riverview) ; University of Sydney, graduating B.Sc. in 1922 ; University of Oxford, postgraduate B.Sc., 1924 ; University of Sydney, D.Sc., 1926 ; and was Demonstrator and Lecturer, 1926–29. Other appointments included Reader in Biology, St. Bartholomew's Hospital Medical School, University of London, 1939–49 ; Challis Professor of Zoology, University of Sydney, 1949–60 ; Reader in Zoology, University of New England, 1960–66 ; and Honorary Research Fellow, University of New England, 1966–67.

Dr. Murray received several honours, including John Coutts Scholarship, University Medal, Linnean Macleay Fellowship (University of Sydney) ; Rockefeller Fellowship (Universities of Freiburg and Cambridge) ; Royal Society Smithson Research Fellowship (Strangeways Laboratory) ; Hon.M.A. (Cantab.). In 1954 he was elected a Fellow of the Australian Academy of Science

His chief research interest was experimental embryology. His first publications (with J. S. Huxley) on this topic appeared in 1925. Much of his work dealt with the development of bone and cartilage.

Dr. Murray's deep understanding and his scholarly approach to problems in general biology are shown in the textbook *Biology*, published in 1950.

Dr. Murray was elected to membership of the Society in 1950, during which period of membership he gave valuable service to the Society, particularly as the representative of the New England Branch, serving on the Council of the Society.

Medallists, 1967-68

Citations

Clarke Medal for 1968

Professor H. G. Andrewartha

Professor H. G. Andrewartha, Professor of Zoology in the University of Adelaide, is a distinguished ecologist. His main contribution has been in developing a general theory of what determines the distribution and the abundance of animals. Much of his work has been done with three native Australian insects : the thrips, the Australian plague locust, and the Australian plague grasshopper. His studies of these insects have not only been of major importance from a theoretical point of view, but have also been important in any application of appropriate measures to reduce their deprecation as pests. Professor Andrewartha is the author of two books and many publications in these fields. He has also written numerous review articles on population biology.

In addition to this, Professor Andrewartha has made some distinguished contributions to the field of ecological physiology, notably his work on insect diapause and on the water relations of insects in dry places. He has, therefore, made a very nice tie-up between physiological studies and population studies based on Australian animals. He must be ranked as one of the outstanding living ecologists. His international reputation is high and his general advice and judgment on ecological issues are widely sought.

The Edgeworth David Medal for 1967

The Edgeworth David Medal for 1967 conjointly to Dr. D. H. Green, Department of Geophysics and Geochemistry, Australian National University, and Dr. W. J. Peacock, C.S.I.R.O., Division of Plant Industry, Canberra.

Dr. D. H. Green

David Headley Green gained the Master of Science degree from the University of Tasmania and the degree of Doctor of Philosophy from the University of Cambridge.

During the very short space of seven years, mostly since his appointment as a Research Fellow in the Research School of Physical Sciences at the Australian National University, he has produced a most impressive series of publications dealing with mineralogy, petrology and geochemistry. These form an outstanding contribution not only to the chemistry of basic and ultrabasic rocks and their magmas, but also to controlled speculation on the physics and chemistry of the mantle and crust and of the relation of these to one another and to orogeny.

The techniques of study used were the most modern. High temperature and pressure experiment and electron probe analysis were combined with a thorough, critical and thoughtful reading and interpretation of the literature. Most of the work was carried out in Australia, even though Dr. Green did take his higher degree at Cambridge.

Dr. W. J. Peacock

Dr. Peacock graduated B.Sc. with First-class Honours in Botany in 1957, before he had reached twenty years of age. During his work for his Ph.D., Dr. Peacock held first a C.S.I.R.O. graduate studentship and was then Macleay Fellow of the Linnean Society.

Early in 1963 Dr. Peacock was awarded a C.S.I.R.O. Overseas Post-doctoral Fellowship, and he used this to work in the University of Oregon with Professor E. Novitsky. After the expiry of the Fellowship he was appointed by the University of Oregon to a Visiting Associate Professorship, which he held for one year, but could have held longer. However, he chose to return to Australia and was given a position in C.S.I.R.O. Division of Plant Industry with the rank of Senior Research Scientist, although he was then only twenty-seven years of age. He remains in this position at the present time.

Dr. Peacock's contributions to biological science can be classified under three headings :

(1) Cytology and related studies of groups of Australian flora.

(2) Studies on the nature of crossing-over and on chromosome structure.

(3) Studies on Meotic Drive.

Dr. Peacock has achieved a world reputation in all three fields. He has been invited to international conferences as guest speaker (for example, Brazil, 1965) and he was responsible, whilst at Oak Ridge, for the initiation of an international conference on Genetic Recombination. This conference is to be held in Canberra in August, 1968. It may be said that in the field of study of genetic recombination he has helped put Australia on the world map.

The Society's Medal for 1967

Arthur Frederick Alan Harper, M.Sc., F.Inst.P., F.A.I.P.

Alan Harper, a Senior Principal Research Scientist in the Division of Physics, National Standards Laboratory, C.S.I.R.O., has been a member of the Society since 1936, served on Council 1955–63, 1966, and was elected President in 1959. He has always been a strong supporter of the Society, and he was a member of the special committee which recently completed the redrafting of the Society's Rules and By-Laws.

As a physicist, Mr. Harper's main interest has been in thermal phenomena, particularly in the field of temperature measurement and in the realization of temperature scales; he has published a number of papers on this subject. He has also made contributions in the fields of humidity, solid state and hypothermia, and has published papers thereon.

Mr. Harper was one of the architects of the Australian Institute of Physics, of which he is currently Vice-President. He is Secretary to the National Standards Commission and is also Technical Consultant to the Senate Select Committee on the Metric System of Weights and Measures. In the international sphere he is a member of the Advisory Committee on Thermometry of the Bureau International des Poids et Mesures and he is the Australian representative on the Organization International de Metrologie Legale.

Archibald D. Ollé Prize

John R. Conolly, B.Sc. (Syd.), Ph.D. (N.S.W.)

John R. Conolly, B.Sc. (Syd.), Ph.D. (N.S.W.) received this award for his paper entitled "Petrology and Origin of the Cocoparra Group, Upper Devonian, New South Wales", published in Volume 100 of "Journal and Proceedings". The background of extensive field and laboratory work involved, the standard and presentation, the positive approach to interpretive stratigraphy and sedimentology and its originality set this paper apart as a major contribution in the broad sense to our geological knowledge. This, together with other published papers, has established Dr. Conolly as the authority on most of the Upper Devonian rocks of New South Wales.

Members of the Society, April, 1969

The year of election to membership and the number of papers contributed to the Society's Journal are shown in brackets, thus : (1934 : P8), * indicates Life Membership.

Honorary Members

BLACKBURN, Sir Charles Bickerton, K.C.M.G., O.B.E., B.A., M.D., Ch.M., 152/177 Bellevue Road, Double Bay (1960).
BRAGG, Sir Lawrence, O.B.E., F.R.S., The Royal Institution of Great Britain, 21 Albemarle Street, Piccadilly, London, W.1, England (1960).
BURNET, Sir Frank Macfarlane, O.M., Kt., D.Sc., F.R.S., F.A.A., c/o Department of Microbiology, University of Melbourne, Parkville, Victoria (1949).

FIRTH, Raymond William, D.Litt., M.A., Ph.D., Professor of Anthropology, University of London, London School of Economics, Houghton Street, Aldwych, W.C.2, England (1952).

O'CONNELL, Rev. Daniel J., S.J., D.Sc., Ph.D., F.R.A.S., Director, The Vatican Observatory, Rome, Italy (1953).
OLIPHANT, Sir Marcus L., K.B.E., Ph.D., B.Sc., F.R.S., F.A.A., Professor of Particle Physics, Australian National University, Canberra, A.C.T. (1948).

ROBINSON, Sir Robert, M.A., D.Sc., F.R.S., F.C.S., F.I.C., Professor of Chemistry, Oxford University, England (1948).

Members

ADAMSON, Colin Lachlan, B.Sc., 43 Holt Avenue, Cremorne (1944).
ADKINS, George Earl, A.S.T.C., A.M.Aus.I.M.M., A.M.I.E.(Aust.), Dip.App.Sc., School of Mining Engineering, University of New South Wales, Kensington (1960).
*ALBERT, Adrien, D.Sc., F.A.A., Professor of Medical Chemistry, Australian National University, Canberra, A.C.T. (1938 : P4).
ALEXANDER, Albert Ernest, Ph.D., F.A.A., Professor of Chemistry, University of Sydney (1950).
ANDERSON, Geoffrey William, B.Sc., c/o P.O. Box 30, Chatswood (1948).
ANDREWS, Paul Burke, B.Sc., 50 Melbourne Road, East Lindfield (1948 : P2).
ARNOT, Richard Hugh Macdonald, B.A., B.Sc.Agr., 2/50 Park Road, Surrey Hills, Victoria (1963).
*ASTON, Ronald Leslie, Ph.D., 39 Redmyre Road, Strathfield (1930 ; President 1948).
*AUROUSSEAU, Marcel, M.C., B.Sc., 229 Woodland Street, Balgowlah (1919 : P2).

BADHAM, Charles David, M.B., B.S., D.R.(Syd.), M.C.R.A., " New Lodge ", 16 Ormonde Parade, Hurstville (1962).
BAKER, Stanley Charles, Ph.D., Department of Physics, University of Newcastle (1934 : P4).
BANFIELD, James Edmund, M.Sc., Ph.D.(Melb.), Department of Organic Chemistry, University of New England, Armidale (1963).
BANKS, Maxwell Robert, B.Sc., Department of Geology, University of Tasmania, Hobart, Tas. (1951).
BASDEN, Kenneth Spencer, Ph.D., B.Sc., Department of Fuel, University of New South Wales, Kensington (1951).
BAXTER, John Philip, K.B.E., C.M.G., O.B.E., Ph.D., F.A.A., Australian Atomic Energy Commission, 45 Beach Street, Coogee (1950).
BEADLE, Noel Charles William, D.Sc., Professor of Botany, University of New England, Armidale (1964).
BEALE, James Edgar Osborne, Solicitor, 166 Keira Street, Wollongong (1968).
BEAVIS, Margaret, B.Sc., Dip.Ed., 3 Rosebank Avenue, Epping (1961).
BELL, Alfred Denys Mervyn, B.Sc.(Hons.), School of Applied Geology, University of New South Wales, Kensington (1960).
*BENTIVOGLIO, Sydney Ernest, B.Sc.Agr., 41 Telegraph Road, Pymble (1926).
BINNS, Raymond Albert, B.Sc.(Syd.), Ph.D.(Cantab.), Associate Professor of Geology, University of New England, Armidale (1964 : P1).
*BISHOP, Eldred George, 2/12 Muston Street, Mosman (1920).
BLANKS, Fred Roy, B.Sc., 19 Innes Road, Greenwich (1948).
BLAYDEN, Ian Douglas, B.Sc.(Hons.), 42 Eleebana Road, Eleebana (1966).
BLUNT, Michael Hugh, M.R.C.V.S., Veterinary Surgeon, 185 Markham Street, Armidale (1961).
BOLT, Bruce Alan, Ph.D., Professor of Seismology, Department of Geology and Geophysics, University of California, Berkeley, U.S.A. (1956 : P3).
BOOKER, Frederick William, D.Sc., 11 Boundary Street, Roseville (1951 : P1).
BOOTH, Robert Kerril, B.Sc., Dip.Ed.(Syd.), Science Teacher, 46 Jellicoe Street, Hurstville (1964).
BRADLEY, Edgar David, M.B., B.S.(Syd.), D.O., Ophthalmologist, 107 Faulkner Street, Armidale (1964).
BRANAGAN, David Francis, M.Sc., Ph.D., Senior Lecturer, Department of Geology and Geophysics, University of Sydney (1967 : P2).
BRENNAN, Edward, B.E.(Appl.Geology), P.O. Box 5, Mount Morgan, Queensland (1962).
BRIDGES, David Somerset, 19 Mount Pleasant Avenue, Normanhurst (1952).
*BRIGGS, George Henry, D.Sc., 13 Findlay Avenue, Roseville (1919 : P1).
BROWN, Desmond J., D.Sc., Ph.D., Department of Medical Chemistry, Australian National University, Canberra, A.C.T. (1942).
BROWN, Kenneth John, A.S.T.C., A.R.A.C.I., 3 Karda Place, Gymea (1963).
BROWNE, Ida Alison, D.Sc., 363 Edgecliff Road, Edgecliff (1935 : P12 ; President 1953).

*Browne, William Rowan, D.Sc., F.A.A., 363 Edgecliff Road, Edgecliff (1913 : P23 ; President 1932).

Bruce, Colin Frank, D.Sc., Physicist, 17 Redan Street, Mosman (1964).

Bryan, John Hamilton, B.Sc.(Hons.), Geologist, 9/90 Raglan Street, Mosman (1968).

Buckley, Lindsay Arthur, B.Sc., 131 Laurel Avenue, Chelmer, Queensland (1940).

Bullen, Keith Edward, Sc.D., F.R.S., F.A.A., Professor of Applied Mathematics, University of Sydney (1946 : P3).

Burg, Raymond Augustine, Senior Analyst, Department of Mines, N.S.W. ; p.r. 17 Titania Street, Randwick (1960).

Burns, Bruce Bertram, D.D.S., Dental Surgeon, Suite 607, T. & G. Building, Park Street, Sydney 1961).

Butland, Gilbert James, B.A., Ph.D., F.R.G.S., Professor of Geography, University of New England, Armidale (1961).

Cameron, John Craig, M.A., B.Sc.(Edin.), D.I.C., 15 Monterey Street, Kogarah (1957).

Campbell, Ian Gavan Stuart, B.Sc., c/o Barker College, Hornsby (1955).

*Carey, Samuel Warren, D.Sc., Professor of Geology, University of Tasmania, Hobart, Tas. (1938 : P2).

Cavill, George William Kenneth, Ph.D., D.Sc., Professor of Organic Chemistry, University of New South Wales, Kensington (1944).

*Chaffer, Edric Keith, 27 Warrane Road, Roseville (1954).

Chalmers, Robert Oliver, Australian Museum, College Street, Sydney (1933 : P1).

Chalmers, Maxwell Clark, B.Sc., 58 Spencer Street, Killara (1940).

Chiarella, Carl, M.Sc., 28 Curban Street, Balgowlah (1967).

Churchward, John Gordon, B.Sc.Agr., Ph.D., c/o The Australian Wheat Board, 528 Lonsdale Street, Melbourne (1935 : P2).

Clancy, Brian Edward, M.Sc., Australian Atomic Energy Commission, Lucas Heights (1957).

Coalstad, Stanton Ernest, B.Sc., Metallurgical Chemist, 16 Station Street, Marrickville (1961).

Cohen, Samuel Bernard, M.Sc., 46 Wolseley Road, Point Piper (1940).

Cole, Edward Ritchie, B.Sc., Associate Professor of Organic Chemistry, University of New South Wales, Kensington (1940 : P2).

Cole, Joyce Marie (Mrs.), B.Sc., 7 Wolsten Avenue, Turramurra (1940 : P1).

Collett, Gordon, B.Sc., 16 Day Road, Cheltenham (1940).

Conaghan, Hugh Francis, M.Sc., Chief Analyst, Department of Mines, N.S.W. ; p.r. 104 Lancaster Avenue, West Ryde (1960).

Conolly, John Robert, B.Sc.(Syd.), Ph.D.(N.S.W.), Department of Geology, University of Southern California, Columbia, S.C., U.S.A. (1963: P4).

Cook, Alan Cecil, M.A.(Cantab.), Wollongong University College ; p.r. Lot 19, Dallas Street, Mt. Ousley (1968 : P1).

Cook, Cyril Lloyd, Ph.D., c/o Propulsion Research Laboratories, Box 1424H, G.P.O., Adelaide, S.A. (1948).

Cortis-Jones, Beverley, M.Sc., 65 Peacock Street, Seaforth (1940).

Coss, Paul, B.Sc., 10 Lucia Avenue, St. Ives (1963).

Cox, Charles Dixon, B.Sc., 51 Darley Street, Forestville (1964).

Crawford, Edwin John, B.E., 7a Battle Boulevarde, Seaforth (1955).

Crawford, Ian Andrew, P.O. Box 635, Burnie, Tas. (1955).

*Cresswick, John Arthur, 101 Villiers Street, Rockdale (1921 : P1).

Croft, James Bernard, B.E., Ph.D., c/o Coffey & Hollingsworth, 12 Waterloo Road, North Ryde (1956).

Crook, Keith Alan Waterhouse, Ph.D., Geology Department, Australian National University, Canberra, A.C.T. (1954 : P9).

Cruikshank, Bruce Ian, B.Sc.(Hons.), 16 Arthur Street, Punchbowl (1965).

Davies, George Frederick, 57 Eastern Avenue, Kingsford (1952).

Davis, Gwenda Louise, B.Sc., Ph.D., Associate Professor, Department of Botany, University of New England, Armidale (1961).

Day, Alan Arthur, Ph.D., F.R.A.S., Department of Geology and Geophysics, University of Sydney (1952 : P1 ; President 1965).

Denton, Leslie A., Bunarba Road, Miranda (1955).

Divnich, George, Engineer Agronom.(Yugoslavia), Engineering Analyst, 90 Highclere Avenue, Punchbowl (1960).

Doherty, Gregory, B.Sc.(Hons.), Australian Atomic Energy Commission, Lucas Heights (1963).

*Donegan, Henry Arthur James, M.Sc., F.R.A.C.I., F.R.I.C., 18 Hillview Street, Sans Souci (1928 : P1 ; President 1960).

Drake, Lawrence Arthur, B.A.(Hons.), B.Sc., Director, Riverview College Observatory, Riverview (1962 : P1).

Drummond, Heather Rutherford, B.Sc., 2 Gerald Avenue, Roseville (1950).

Dulhunty, John Allan, D.Sc., Department of Geology and Geophysics, University of Sydney (1937 : P22 ; President 1947).

Eade, Ronald Arthur, Ph.D., School of Organic Chemistry, University of New South Wales, Kensington (1945).

Edgar, Joyce Enid (Mrs.), B.Sc., 12 Calvert Avenue, Killara (1951).

*Elkin, Adolphus Peter, C.M.G., Ph.D., Emeritus Professor, 15 Norwood Avenue, Lindfield (1934 : P4 ; President 1940).

Ellison, Dorothy Jean, M.Sc., 45 Victoria Street, Roseville (1949).

Emerson, Donald Westland, M.Sc., B.E.(Appl.Geol.), Department of Geology and Geophysics, University of Sydney (1966 : P1).

Emmerton, Henry James, B.Sc., 37 Wangoola Street, East Gordon (1940).

Engel, Brian Adolph, M.Sc., Geology Department, University of Newcastle (1961 : P1).

Evans, Phillip Richard, B.A.(Oxon.), Ph.D.(Bristol), Esso Palynology Laboratory, School of Applied Geology, University of New South Wales (1968).

Everett, Frederick A., B.Sc., Jannali Boys' High School, Jannali (1963).

Facer, Richard Andrew, B.Sc.(Hons.), Department of Geology, Wollongong University College, Wollongong (1965 : P1).

Fallon, Joseph James, Loch Maree Place, Vaucluse (1950).

Fayle, Rex Dennes Harris, Pharmaceutical Chemist, 141 Jeffrey Street, Armidale (1961).

FEATHER, Norman Thomas, B.A., M.A., Ph.D., Dip.Ed., Associate Professor of Psychology, University of New England Armidale (1966).

FISHER, Robert, B.Sc., 3 Sackville Street, Maroubra (1940).

FLEISCHMANN, Arnold Walter, 5 Erang Street, Carss Park (1956 : P1).

FLETCHER, Harold Oswald, M.Sc., 131 Milson Road, Cremorne (1933).

FLETCHER, Neville Horner, B.Sc., M.A., Ph.D., Professor of Physics, University of New England, Armidale (1961).

FOLDVARY, Gabor Zoltan, B.Sc., 267 Beauchamp Road, Matraville (1965).

FRENCH, Oswald Raymond, 6 Herberton Avenue, Hunters Hill (1951).

FRIEND, James Alan, Ph.D., Professor of Chemistry, University of West Indies, St. Augustine, Trinidad, W.I. (1944 : P2).

FURST, Hellmut Friedrich, D.M.D.(Hamburg), 185 Elizabeth Street, Sydney (1945).

GALLOWAY, Malcolm Charles, B.Sc., Geologist, 17 Johnson Street, Chatswood (1960 : P1).

GARRETTY, Michael Duhan, D.Sc., Box 763, G.P.O., Melbourne, Vic. (1935 : P2).

GASCOIGNE, Robert Mortimer, Ph.D., Department of Philosophy, University of New South Wales, Kensington (1939 : P4).

GELLERT, Emery, Dr.phil.(Basle), 38 Toorak Avenue, Wollongong (1968).

GIBBONS, George Studley, M.Sc., 75 Nicholson Street, St. Leonards (1966).

GIBSON, Neville Allan, Ph.D., 103 Bland Street, Ashfield (1942 : P6).

GILES, Edward Thomas, M.Sc., Ph.D., D.I.C., F.R.E.S., Professor of Zoology, University of New England, Armidale (1961).

GILKS, Arthur Joseph, B.Sc., Lecturer in Mathematics, R.A.N. College, Jervis Bay (1968).

*GILL, Stuart Frederic, 45 Neville Street, Marrickville (1947).

GLASSON, Kenneth Roderick, B.Sc., Ph.D., 70 Beecroft Road, Beecroft (1948 : P1).

GOLDING, Henry George, M.Sc., Ph.D., School of Applied Geology, University of New South Wales, Kensington (1953 : P4).

GOLDSTONE, Charles Lillington, B.Sc.Agr.(N.Z.), School of Wool Technology, University of New South Wales, Kensington (1951).

GOODWIN, Robert Henry, B.Sc., M.Sc., Geologist, 2/1 Musgrave Street, Mosman (1968).

GORDIJEW, Gurij, Engineer Hydro Geology (Inst. Hydro Meteorology in Moscow, 1936), 41 Abbotsford Road, Homebush (1962).

GOW, Neil Neville, B.Sc.(Hons.) (1966).

GRAHAME, Mervyn Ernest, B.A., Schoolteacher, 161 Parry Street, Hamilton (1959).

GRANT, John Narcissus Guerrato, Dip.Eng., 37 Chalayer Street, Rose Bay (1961).

GRAY, Charles Alexander Menzies, B.E., M.E., Professor of Engineering, Wollongong University College, Wollongong (1948 : P1).

GRAY, Noel Macintosh, B.Sc., 1 Centenary Avenue, Hunters Hill (1952).

GRIFFIN, Russell John, B.Sc. (1952).

GRIFFITH, James Langford, B.A., M.Sc., Associate Professor of Mathematics, University of New South Wales, Kensington, (1952 : P16 ; President 1958).

GRODEN, Charles Mark, M.Sc., School of Mathematics, University of New South Wales, Kensington (1957 : P3).

GUTMANN, Felix, Ph.D., 70A Victoria Road, West Pennant Hills (1946 : P1).

GUTSCHE, Herbert William, B.Sc., School of Earth Sciences, Macquarie University, North Ryde (1961).

GUY, Brian Bertram, B.Sc.(Syd.), Ph.D.(Syd.), Department of Geology and Geophysics, University of Sydney (1968 : P1).

HACKETT, Ian Harry, B.Sc.(Chem.Eng.), Research Chemist, 24 Military Road, Merrylands (1968).

HALL, Brian Keith, Ph.D.(U.N.E.), B.Sc.(Hons.), Assistant Professor of Biology, Dalhousie University, Halifax, Nova Scotia, Canada (1967).

HALL, Francis Michael, M.Sc., A.S.T.C., Chemistry Department, Wollongong University College, Wollongong (1968).

HALL, Norman Frederick Blake, M.Sc., 16A Wharf Road, Longueville (1934).

HAMILTON, Lloyd, B.E., 64 Finlayson Street, Lane Cove (1965).

HAMPTON, Edward John William, 1 Hunter Street, Waratah (1949).

HANCOCK, Harry Sheffield, M.Sc., 16 Koora Avenue, Wahroonga (1955).

HANLON, Frederick Noel, B.Sc., 31 Congewoi Road, Mosman (1940 : P14 ; President 1957).

HARDWICK, Reginald Leslie, B.Sc., Visual Aids Officer, 183 Richmond Road, Kingswood (1968).

HARPER, Arthur Frederick Alan, M.Sc., National Standards Laboratory, University Grounds, City Road, Chippendale (1936 : P1 ; President 1959).

HARRIS, Clive Melville, Ph.D., Associate Professor of Chemistry, University of New South Wales, Kensington (1948 : P6).

HARRISON, Ernest John Jasper, B.Sc., N.S.W. Geological Survey, Department of Mines, Sydney (1946).

HAYDON, Sydney Charles, M.A., Ph.D., F.Inst.P., Professor of Physics, University of New England, Armidale (1965).

*HAYES, Daphne (Mrs.), B.Sc., 412/108 Elizabeth Bay Road, Elizabeth Bay (1943).

HELBY, Robin James, M.Sc., 344 Malton Road, North Epping (1966 : P1).

HENDERSON, Roger John, B.Sc.(Hons.), Lecturer in Exploration Geophysics, School of Earth Sciences, Macquarie University, North Ryde (1966).

HIGGS, Alan Charles, c/o Colonial Sugar Refining Co. Ltd., Building Material Division, 1–7 Bent Street, Sydney (1945).

HILL, Dorothy, D.Sc., F.R.S., F.A.A., Professor of Geology and Mineralogy, University of Queensland, St. Lucia, Brisbane (1938 : P6).

HILL, Helen Campbell (Mrs.), 14 Miowera Road, North Turramurra (1951).

HODGINS, Reginald William, A.S.T.C., B.Sc., Engineering Analyst Department of Main Roads, N.S.W. ; p.r. 57 Home Street, Port Macquarie (1967).

*HOGARTH, Julius William, B.Sc., 4 " Hillsmore ", 20 Joubert Street, Hunters Hill (1948 : P6).

HORNE, Allan Richard, 149A Hawkesbury Road, North Springwood (1960).

HOWE, Bernard Adrian, c/o Exploration Physics, 265 Old Canterbury Road, Dulwich Hill (1963).

HUMPHRIES, John William, B.Sc., Physicist, National Standards Laboratory, University Grounds, City Road, Chippendale (1959 : P1 ; President 1964).

*Hynes, Harold John, D.Sc.Agr., 7 Futuna Street, Hunters Hill (1923 : P3).

Iredale, Thomas, D.Sc., 8 Nulla Nulla Street, Turramurra (1943).

Jaeger, John Conrad, D.Sc., F.A.A., Geophysics Department, Australian National University, Canberra, A.C.T. (1942 : P1).
Jenkins, Thomas Benjamin Huw, Ph.D., Department of Geology and Geophysics, University of Sydney (1956).
Jones, James Rhys, 25 Boundary Road, Mortdale (1959).
Joplin, Germaine Anne, D.Sc., Geophysics Department, Australian National University, Canberra, A.C.T. (1935 : P10).

Keane, Austin, Ph.D., Professor of Mathematics, Wollongong University College, Wollongong (1955 : P4 ; President 1968).
Kemp, William Ronald Grant, B.Sc., Physicist, 16 Fig Tree Street, Lane Cove (1960).
Kimble, Jean Annie, B.Sc., 2/163 Homer Street, Earlwood (1943).
*Kirchner, William John, B.Sc., " Fairways ", Linkview Avenue, Blackheath (1920).
Kitamura, Torrence Edward, B.A., B.Sc.Agr., 18 Pullbrook Parade, Hornsby (1964).
Koch, Leo E., D.Phil.Habil., School of Applied Geology, University of New South Wales, Kensington (1948).
Korber, Peter Henry Wilibald, B.Sc., Analytical Chemist, 14/20 Warwick Avenue, Cammeray (1968).
Krysko v. Tryst, Maren (Mrs.), B.Sc., Grad.Dip., School of Applied Geology, University of New South Wales, Kensington (1959).

Lack, N. Edith (Mrs.), 471 Sailor's Bay Road, Northbridge (1968).
Lambeth, Arthur James, B.Sc., " Talanga ", Picton Road, Douglas Park, N.S.W. (1939 : P3).
Landecker, Kurt, D.Ing.(Berlin), Department of Physics, University of New England, Armidale (1961).
Lassak, Erich Vincent, M.Sc.(N.S.W.), B.Sc.(Hons.), A.S.T.C., Research Chemist, 167 Berowra Waters Road, Berowra (1964 : P1).
Lawrence, Laurence James, D.Sc., Ph.D., Associate Professor, School of Applied Geology, University of New South Wales, Kensington (1951 : P4).
Leaver, Gaynor Eiluned (Mrs.), B.Sc.(Wales), F.G.S.(Lond.), 30 Ingalara Avenue, Wahroonga (1961).
Le Fevre, Raymond James Wood, D.Sc., F.R.S., F.A.A., Professor and Head of the School of Chemistry, University of Sydney (1947 : P4 ; President 1961).
Lemberg, Max Rudolph, D.Phil., F.R.S., F.A.A., Assistant Director, Institute of Medical Research, Royal North Shore Hospital, St. Leonards (1936 : P3 ; President 1955).
*Lions, Francis, Ph.D., 44/630 Pacific Highway, Killara (1929 : P56 ; President 1946).
Lions, Jean Elizabeth (Mrs.), B.Sc., 44/630 Pacific Highway, Killara (1940).
Lloyd, James Charles, B.Sc., 1 Spurwood Road, Turramurra (1947).
Lockwood, William Hutton, B.Sc., Institute of Medical Research, Royal North Shore Hospital, St. Leonards (1940 : P1).
Lovering, John Francis, Ph.D., Professor of Geology, University of Melbourne, Parkville, Vic. (1951 : P4).
Low, Angus Henry, Ph.D., Associate Professor, Department of Applied Mathematics, University of New South Wales, Kensington (1950 : P4 ; President 1967).
Lowenthal, Gerhard, Ph.D., M.Sc., 17 Gnarbo Avenue, Carss Park (1959).
Lyons, Lawrence Ernest, Ph.D., Professor of Chemistry, University of Queensland, St. Lucia, Brisbane (1948 : P3).

Maccoll, Allan, M.Sc., Department of Chemistry, University College, Gower Street, London, W.C.1, England (1939 : P4).
McCarthy, Frederick David, Dip.Anthr., Principal, Australian Institute of Aboriginal Studies, Box 553, City P.O., Canberra, A.C.T. (1949 : P1 ; President 1956).
McClymont, Gordon Lee, B.V.Sc., Ph.D., Professor of Rural Science, University of New England, Armidale (1961).
McCoy, William Kevin, 86 Ave Da Republica, Macao, via Hong Kong (1943).
McCullagh, Morris Behan (1950).
McElroy, Clifford Turner, Ph.D., M.Sc., Director, Geological Survey of N.S.W., P.O. Box R 216, Royal Exchange, Sydney (1949 : P2).
McGlynn, John Albert, B.Sc.(Hons.), Analyst, Department of Mines, N.S.W., Sydney (1964).
McGregor, Gordon Howard, 4 Maple Avenue, Pennant Hills (1940).
McKay, Maxwell Herbert, M.A., Ph.D., Professor of Mathematics, University of Papua and New Guinea, Boroko, T.P.N.G. (1956 : P1).
McKern, Howard Hamlet Gordon, M.Sc., F.R.A.C.I., Museum of Applied Arts and Sciences, Harris Street, Broadway, Sydney (1943 : P12 ; President 1963).
McMahon, Barry Keys, B.Sc. (1961).
McMahon, Patrick Reginald, Ph.D., Professor of Wool Technology, University of New South Wales, Kensington (1947).
McNamara, Barbara Joyce (Mrs.), M.B., B.S., c/o Dr. B. Burfitt, Callan Park Hospital, Rozelle (1943).
MacKellar, Michael John Randal, B.Sc.Agr.(Syd.), B.A.(Hons.) (Oxon.), Agricultural Scientist, 1/47 Wolseley Road, Mosman (1968).
Magee, Charles Joseph, D.Sc.Agr., 57 Florida Road, Palm Beach (1947 : P2 ; President 1952).
Majstrenko, Petro, M.Sc.(Copenhagen), Lecturer in Mathematics, University of New England, Armidale (1966).
Males, Pamela Ann, 13 Gelding Street, Dulwich Hill (1951).
Manser, Warren, B.Sc.(Syd.), Department of Earth Sciences, University of Papua and New Guinea, Boroko, T.P.N.G. (1964).
Marsden, Joan Audrey, A.S.T.C.(Dip.App.Chem.), 203 West Street, Crows Nest (1955).
Marshall, Charles Edward, D.Sc., Professor of Geology and Geophysics, University of Sydney (1949 : P1).
Martin, Peter Marcus, M.Sc.Agr., Dip.Ed., Lecturer, Botany Department, University of Sydney (1968).
Meares, Harry John Devenish, 27 Milray Avenue, Wollstonecraft (1949).
*Mellor, David Paver, Professor of Inorganic Chemistry, University of New South Wales, Kensington (1929 : P25 ; President 1941).

Millership, William, M.Sc., 18 Courallie Avenue, Pymble (1940).
Minty, Edward James, M.Sc., B.Sc., Dip.Ed., 36 Castle Street, Castle Hill (1951 : P2).
Moelle, Konrad Heinrich Richard, Absolutorium (Innsbruck), Ph.D.(Innsbruck), Lecturer in Geology, University of Newcastle ; p.r. 2 Hillcrest Road, Merewether (1967).
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Mort, Francis George Arnot, 29 Preston Avenue, Fivedock (1934).
Mosher, Kenneth George, B.Sc., 9 Yirgella Avenue, Killara (1948).
Moss, Francis John, M.B., B.S., Department of Biochemistry, University of New South Wales, Kensington (1955).
Moye, Daniel George, B.Sc., 36 Sylvander Street, North Balwyn, Vic. (1944).
*Murphy, Robert Kenneth, Dr.Ing.Chem., 68 Pindari Avenue, North Mosman (1915).
Murray, Jascha Ann (Mrs.), M.Sc., Strangeways Research Laboratory, Wort's Causeway, Cambridge, England (1961).

Nashar, Beryl, Ph.D., Professor of Geology, University of Newcastle ; p.r. 15 Princeton Avenue, Adamstown Heights (1946 : P2).
*Naylor, George Francis King, Ph.D., Department of Psychology and Philosophy, University of Queensland, St. Lucia, Brisbane (1930 : P7).
*Neuhaus, John William George, M.Sc., 32 Bolton Street, Guildford (1943).
*Newman, Ivor Vickery, Ph.D., School of Biology, Macquarie University, North Ryde (1932).
Noakes, Lyndon Charles, B.A., Bureau of Mineral Resources, Geology and Geophysics, Canberra, A.C.T. (1945 : P1).
*Noble, Robert Jackson, Ph.D., 32a Middle Harbour Road, Lindfield (1920 : P4 ; President 1934).
Nyholm, Sir Ronald Sydney, D.Sc., F.R.S., Professor of Inorganic Chemistry, University College, Gower Street, London, W.C.1, England (1940 : P26 ; President 1954).

O'Farrell, Antony Frederick Louis, A.R.C.Sc., B.Sc., Professor of Zoology, University of New England, Armidale (1961).
O'Halloran, Peter Joseph, B.Sc., Dip.Ed., M.Sc., In charge of Mathematics Department, R.A.N. College, Jervis Bay (1968).
Old, Adrian Noel, B.A., B.Sc.Agr., Senior Chemist, N.S.W. Department of Agriculture ; p.r. 13 Fallon Street, Rydalmere (1947).
Oxenford, Reginald Augustus, B.Sc., 10 Greaves Street, Grafton (1950).

Packham, Gordon Howard, Ph.D., Department of Geology and Geophysics, University of Sydney (1951 : P4).
Pearce, Marcelle Gordon Ivy, M.Sc.(Melb.), Experimental Officer, C.S.I.R.O., Division of Applied Physics ; p.r. 108 Burns Road, Wahroonga (1967).
*Penfold, Arthur Ramon, Flat 516, Baroda Hall, 6a Birtley Place, Elizabeth Bay (1920 : P82 ; President 1935).
Perry, Hubert Roy, B.Sc., 74 Woodbine Street, Bowral (1948).
Petersen, George Arthur, B.Sc., B.E., 55 Roseville Avenue, Roseville (1966).
Philip, Graeme Maxwell, M.Sc.(Melb.), Ph.D. (Cantab.), F.G.S., Professor of Geology, University of New England, Armidale (1964 : P1).
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Phipps, Charles Verling Gayer, Ph.D., Department of Geology and Geophysics, University of Sydney (1960).
Pickett, John William, M.Sc.(N.E.), Dr.phil.nat. (Frankfurt/M), Palaeontologist, N.S.W. Geological Survey, Mining Museum, 28 George Street North, Sydney (1965).
Pinwill, Norman, B.A., The Scots College, Victoria Road, Bellevue Hill (1946).
Plummer, Brian Alfred George, M.A., F.R.G.S., Department of Geography, University of New England, Armidale (1961).
Poggendorff, Walter Hans George, B.Sc.Agr., 85 Beaconsfield Road, Chatswood (1949).
Pollard, John Percival, M.Sc.(N.S.W.), Dip.App.Chem.(Swinburne), Mathematician with the Australian Atomic Energy Commission ; p.r. 25 Nabiac Avenue, Gymea (1963).
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Priddle, Raymond Arthur, B.E., 34 Cleveland Street, Wahroonga (1956).
Priestley, John Henry, M.B., B.S., B.Sc., Medical Practitioner, 137 Dangar Street, Armidale (1961).
Prokhovnik, Simon Jacques, M.A., B.Sc., School of Mathematics, University of New South Wales, Kensington (1956 : P3).
*Proud, John Seymour, B.E., Finlay Road, Turramurra (1945).
Puttock, Maurice James, B.Sc.(Eng.), A.Inst.P., Principal Research Officer, C.S.I.R.O., Sydney ; p.r. 2 Montreal Avenue, Killara (1960).

*Quodling, Florrie Mabel, Ph.D., B.Sc., 145 Midson Road, Epping (1935 : P5).

Rade, Janis, M.Sc., Consulting Geologist, Box 5440C, G.P.O., Melbourne (1953 : P6).
Ramm, Eric John, Experimental Officer, Australian Atomic Energy Commission, Lucas Heights (1959).
Rattigan, John Herbert, Ph.D., M.Sc. (1966 : P2).
*Rayner, Jack Maxwell, O.B.E., B.Sc., 5 Tennyson Crescent, Forrest, Canberra, A.C.T. (1931 : P1).
Read, Harold Walter, B.Sc., 1/29 Spinks Road, Corrimal (1962 : P1).
Reichel, Alex, Ph.D., M.Sc., Department of Applied Mathematics, University of Sydney (1957 : P4).
Rice, Thomas Denis, B.Sc., 24 Alliott Street, Campbelltown (1964).
Rigby, John Francis, B.Sc.(Melb.) (1963).
Riggs, Noel Victor, B.Sc.(Adel.), Ph.D.(Cantab.), F.R.A.C.I., Associate Professor of Organic Chemistry, University of New England, Armidale (1961).
Ritchie, Arthur Sinclair, M.Sc., Associate Professor of Geology, University of Newcastle (1947 : P2).
Ritchie, Ernest, D.Sc., F.A.A., Chemistry Department, University of Sydney (1939 : P19).

ROBBINS, Elizabeth Marie (Mrs.), M.Sc., Waterloo Road, North Ryde (1939 : P3).
ROBERTS, Herbert Gordon, B.Sc., c/o Anaconda Aust., Inc., 34 Hunter Street, Sydney (1957).
ROBERTS, John, Ph.D., Bureau of Mineral Resources, Geology and Geophysics, Box 378, Canberra City, A.C.T. (1961 : P3).
ROBERTSON, William Humphrey, B.Sc., c/o Sydney Observatory, Sydney (1949 : P28).
ROBINSON, David Hugh, A.S.T.C., Chemist, 12 Robert Road, West Pennant Hills (1951).
ROPER, Geoffrey Harold, M.Sc., Ph.D., Associate Professor, School of Chemical Engineering, University of New South Wales (1966).
ROSENBAUM, Sidney, 5 Eton Road, Lindfield (1940).
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ROSS, Victoria (Mrs.), M.Sc., B.Sc.(Hons.), " Merroo ", Mill Road, Kurrajong (1960).
ROUNTREE, Phyllis Margaret, D.Sc., Royal Prince Alfred Hospital, Sydney (1945).
ROYLE, Harold George, M.B., B.S.(Syd.), 161 Rusden Street, Armidale (1961).

SAPPAL, Krishna Kumar, M.Sc., Geologist, c/o Department of Geology, Nagpur University, Nagpur, India (1966).
*SCAMMELL, Rupert Boswood, B.Sc., 10 Buena Vista Avenue, Clifton Gardens (1920).
SCHOLER, Harry Albert Theodore, M.Eng., Civil Engineer, c/o Harbours and Rivers Branch, Public Works Department, N.S.W., Phillip Street, Sydney (1960).
SCOTT, John Alan Belmore, B.Sc.(Qld.), 193 Forest Road, Kirrawee (1964).
SEE, Graeme Thomas, B.Sc., School of Nuclear Chemistry, University of New South Wales, Kensington (1949).
SELBY, Edmond Jacob, P.O. Box 121, North Ryde (1933).
*SHARP, Kenneth Raeburn, B.Sc., Engineering Geology Branch, Snowy Mountains Authority, North Cooma (1948).
SHAW, Stirling Edward, B.Sc.(Hons.), Ph.D., F.G.A.A., School of Earth Sciences, Macquarie University, North Ryde (1966).
SHERRARD, Kathleen Margaret (Mrs.), M.Sc., 43 Robertson Road, Centennial Park (1936 : P6).
SHERWIN, Lawrence, B.Sc.(Hons.)(Syd.), 186 Sylvania Road, Miranda (1967).
SIMMONS, Lewis Michael, Ph.D., The Scots College, Victoria Road, Bellevue Hill (1945 : P3).
SIMS, Kenneth Patrick, B.Sc., 25 Fitzpatrick Avenue East, French's Forest (1950 : P14).
SLADE, George Hermon, B.Sc., W. Hermon Slade & Co. Pty. Ltd., Mandemar Avenue, Homebush (1933).
SLADE, Milton John, B.Sc., Dip.Ed.(Syd.), M.Sc.(N.E.), 162 Donnelly Street, Armidale (1952).
SMITH, Ann Ruth (Mrs.), B.Sc., Box 134, P.O., Queenstown, Tas. (1959).
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SMITH, William Eric, Ph.D.(N.S.W.), M.Sc.(Syd.), B.Sc.(Oxon.), Associate Professor of Applied Mathematics, University of New South Wales, Kensington (1963 : P1).
SMITH-WHITE, William Broderick, M.A., Associate Professor of Mathematics, University of Sydney (1947 : P4 ; President 1962).
SOUTH, Stanley Arthur, B.Sc., Geologist, 47 Miowera Road, Turramurra (1967).
STANTON, Richard Limon, Ph.D., Associate Professor of Geology, University of New England, Armidale (1949 : P2).
STAPLEDON, David Hiley, B.Sc., 61 Francis Street, Brighton, South Australia (1954).
STEPHENS, James Norrington, M.A.(Cantab.), Ph.D., 170 Broker's Road, Mt. Pleasant, Wollongong (1959).
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STEVENSON, Barrie Stirling, B.E. (Mech. and Elec.) (Syd.), 21 Glendower Street, Eastwood (1964).
STOCK, Alexander, D.Phil., Ph.D., Professor of Zoology, University of New England, Armidale (1961).
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STRUSZ, Desmond Leslie, Ph.D., B.Sc., Bureau of Mineral Resources, Geology and Geophysics, Canberra, A.C.T. (1960 : P3).
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SURRY, Charles (1961).
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TILLEY, Philip Damien, B.A., Dr.Phil., Department of Geography, University of Sydney (1967).
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UPFOLD, Robert William, B.E., M.E., Department of Engineering, Wollongong University College, Wollongong (1968).

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Veevers, John James, Ph.D., School of Earth Sciences, Macquarie University, North Ryde (1953).
Vernon, Ronald Holden, Ph.D., M.Sc., School of Earth Sciences, Macquarie University, North Ryde (1958 : P1).
Vickery, Joyce Winifred, M.B.E., D.Sc., 17 The Promenade, Cheltenham (1935).
Voisey, Alan Heywood, D.Sc., Professor of Geology and Head of the School of Earth Sciences, Macquarie University, North Ryde (1933 : P13 ; President 1966).
*Vonwiller, Oscar U., B.Sc., Emeritus Professor, " Rathkells ", Kangaroo Valley, N.S.W. (1903 : P10 ; President 1940).

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*Walkom, Arthur Bache, D.Sc., 5/521 Pacific Highway, Killara (1919 and previous membership 1910–1913 : P2 ; President 1943).
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Ward, Judith (Mrs.), B.Sc., 16 Mortimer Avenue, Newtown, Hobart, Tas. (1948).
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Warris, Bevan Jon, B.Sc., c/o ESSO Exploration, Box 4049, G.P.O., Sydney (1967).
Wass, Robin Edgar, Ph.D.(Syd.), B.Sc.(Hons.)(Qld.), Department of Geology and Geophysics, University of Sydney (1965 : P1).
*Waterhouse, Lionel Lawry, B.E.(Syd.), 42 Archer Street, Chatswood (1919 : P1).
*Waterhouse, Walter L., C.M.G., M.C., D.Sc.Agr., F.A.A., 30 Chelmsford Avenue, Lindfield (1919 : P7 ; President 1937).
Watton, Edward Charlton, Ph.D., B.Sc.(Hons.), A.S.T.C., 47 Centennial Avenue, Lane Cove (1963).
Webby, Barry Deane, Ph.D., M.Sc., Department of Geology and Geophysics, University of Sydney (1966).
West, Norman William, B.Sc., c/o Department of Main Roads, Sydney ; p.r. 9/62 Murdoch Street, Cremorne (1954).
Westheimer, Gerald, Ph.D., Professor of Optometry University of California, Berkeley 4, California, U.S.A. (1949).
Wheelhouse, Frances, Senior Laboratory Technician, School of Biological Sciences, University of New South Wales, Kensington (1968).
Whitley, Alice, M.B.E., Ph.D., 39 Belmore Road, Burwood (1951).
Whitley, Gilbert Percy, F.R.Z.S., Honorary Associate of the Australian Museum, College Street, Sydney (1963).
Whitworth, Horace Francis, M.Sc., 31 Sunnyside Crescent, Castlecrag (1951 : P4).
Wilkins, Coleridge Anthony, Ph.D., M.Sc., Department of Mathematics, Wollongong University College, Wollongong (1960 : P2).
Wilkinson, John Frederick George, M.Sc.(Qld.), Ph.D.(Cantab.), Associate Professor of Geology, University of New England, Armidale (1961 : P1).
Williams, Benjamin, 12 Cooke Way, Epping (1949).
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Wilson, Christopher John Lascelles, B.Sc., Department of Geophysics and Geochemistry, Australian National University (1967 : P1).
Winch, Denis Edwin, Ph.D., M.Sc., Senior Lecturer in Applied Mathematics, University of Sydney (1968).
Wood, Clive Charles, Ph.D., B.Sc. (1954).
Wood, Harley Weston, D.Sc., M.Sc., Government Astronomer, Sydney Observatory, Sydney (1936 : P16 ; President 1949).
Wopfner, Helmut, Ph.D., Supervising Geologist, S.A. Geological Survey, S.A. Department of Mines, Box 38, Rundle Street P.O., Adelaide, S.A. (1966 : P1).
Wright, Anthony James, Ph.D., B.Sc., Department of Geology, Victoria University of Wellington, Wellington, N.Z. (1961).
Wylie, Russell George, Ph.D., M.Sc., Physicist, National Standards Laboratory, University Grounds, City Road, Chippendale (1960).

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Associates

Collins, Angus Robert, 16 Hull Road, Beecroft (1965).

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Donegan, Elizabeth (Mrs.), 18 Hillview Street, Sans Souci (1956).

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Griffith, Elsie A. (Mrs.), 9 Kanoona Street, Caringbah (1956).
Gunthorpe, Robert John, B.Sc.(Hons.), Department of Geology, University of New England, Armidale (1965).

Leaver, Harry, B.A., B.Sc., M.B., Ch.M., M.R.C.O.G., F.G.S., 30 Ingalara Avenue, Wahroonga (1962).
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Stokes, Jean Mary (Mrs.), M.Sc., 45 Garibaldi Street, Armidale (1961).

Willey, Helen Ann (Mrs.), B.Sc., Department of Geology, University of New England, Armidale (1965).

Obituary

1966-67

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Henry J. MELDRUM (1912).
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Journal and Proceedings, Royal Society of New South Wales, Vol. 102, pp. 109–117, 1969

Precise Observations of Minor Planets at Sydney Observatory during 1967 and 1968

W. H. Robertson

The programme of precise observations of selected minor planets which was begun in 1955 is being continued and the results for 1967 and 1968 are given here. The methods of observation and reduction were described in the first paper (Robertson, 1958). All the plates were taken with the 23 cm. camera (scale 116″ to the millimetre). Four exposures were made on each plate. The plates for 4 Vesta were taken with a coarse wire grating placed in front of the lens, giving first order spectra which are 2·3 magnitudes fainter than the central image and displaced 0·32 mm. from it in an east-west direction. The spectra were measured for the planet and the central image for the stars.

In Table I are given the means for all four images for the separate groups of stars at the mean of the times. The differences between the results average $0^s{\cdot}033 \sec \delta$ in right ascension and $0''{\cdot}34$ in declination. This corresponds to probable errors for the mean of the two results from one plate of $0^s{\cdot}014 \sec \delta$ and $0''{\cdot}14$. The result for the first two exposures was compared with that from the last two by adding the movement computed from the ephemeris. The means of the differences were $0^s{\cdot}012 \sec \delta$ in right ascension and $0''{\cdot}13$ in declination. It is expected that the two results from each plate will be combined into one when they are used. However, they are published in the present form so that any alteration of the positions of the reference stars can be conveniently applied by using the dependences from Table II. No correction has been applied for aberration, light time or parallax but the factors give the parallax correction when divided by the distance. The observers at the telescope were W. H. Robertson (R), K. P. Sims (S) and Harley Wood (W).

The plates are now measured in a Grubb Parsons coordinate measuring machine in which the bisection is performed photoelectrically by scanning the image of the star under observation over a pair of slits by means of a rotating plate. The correctness of bisection is determined by the equality of two pulses on the screen of a cathode ray oscilloscope. The measuring system consists of two diffraction gratings at right angles which are read by Moiré fringe counting directly to 1 micron.

In accordance with the recommendation of Commission 20 of the International Astronomical Union, Table II gives for each observation the positions of the reference stars and the dependences. The columns headed " R.A." and " Dec." give the seconds of time and arc with proper motion correction applied to bring the catalogue position to the epoch of the plate. The column headed " Star " gives the number from the Yale Catalogue (Vols. 11, 12, 13, 14, 16, 17, 20, 21, 28) and the Cape Catalogue (Vols. 17, 18). The plates were measured by Miss R. Bull, Miss D. Hare, Miss J. Phillips, Miss D. Robinson, Mrs. B. Stolk and Miss E. Wiegold, who have also assisted with the reductions.

Reference

Robertson, W. H., 1958. *J. Roy. Soc. N.S.W.*, **92**, 18. Sydney Observatory Papers No. 33.

Table I

No.			R.A. (1950·0) h	m	s	Dec. (1950·0) °	′	″	Parallax Factors s	″	
		4 Vesta									
		1967 U.T.									
813	Mar.	16·77236	15	55	40·268	−10	50	30·68	+0·032	−3·41	S
814	Mar.	16·77236	15	55	40·308	−10	50	31·59			
815	Mar.	20·75394	15	57	47·692	−10	46	20·68	+0·007	−3·42	W

TABLE I—*continued*

No.			R.A. (1950·0) h	m	s	Dec. (1950·0) °	′	″	Parallax Factors s	″	
		4 Vesta—*continued*									
816	Mar.	20·75394	15	57	47·666	−10	46	20·22			
817	April	04·72026	16	01	29·428	−10	20	27·34	+0·019	−3·48	S
818	April	04·72026	16	01	29·431	−10	20	26·78			
819	April	12·69775	16	00	28·420	−10	01	52·22	+0·019	−3·52	W
820	April	12·69775	16	00	28·386	−10	01	52·26			
821	April	17·67720	15	58	46·247	−09	49	31·20	+0·001	−3·55	R
822	April	17·67720	15	58	46·172	−09	49	31·12			
823	April	27·64716	15	53	04·689	−09	25	18·39	+0·005	−3·60	S
824	April	27·64716	15	53	04·640	−09	25	18·58			
825	May	03·62672	15	48	24·139	−09	12	27·36	+0·003	−3·63	W
826	May	03·62672	15	48	24·129	−09	12	27·48			
827	May	09·60249	15	43	01·578	−09	02	02·67	−0·010	−3·66	R
828	May	09·60249	15	43	01·588	−09	02	03·08			
829	May	17·56909	15	35	14·718	−08	53	43·32	−0·029	−3·68	S
830	May	17·56909	15	35	14·683	−08	53	43·44			
831	May	25·55138	15	27	25·232	−08	53	31·38	0·000	−3·68	W
832	May	25·55138	15	27	25·232	−08	53	30·68			
833	May	29·53707	15	23	43·366	−08	56	50·56	−0·002	−3·67	R
834	May	29·53707	15	23	43·384	−08	56	50·24			
835	June	30·43365	15	07	38·738	−10	50	05·96	−0·018	−3·40	R
836	June	30·43365	15	07	38·662	−10	50	06·09			
837	July	06·42500	15	08	03·849	−11	26	09·82	+0·006	−3·32	R
838	July	06·42500	15	08	03·812	−11	26	10·01			
839	July	11·40830	15	09	15·885	−11	58	47·28	−0·007	−3·24	W
840	July	11·40830	15	09	15·862	−11	58	47·36			
841	July	19·38907	15	12	43·696	−12	55	02·42	−0·006	−3·11	R
842	July	19·38907	15	12	43·672	−12	55	02·60			
843	Aug.	03·36922	15	23	49·678	−14	49	19·02	+0·037	−2·84	W
844	Aug.	03·36922	15	23	49·668	−14	49	18·06			
845	Aug.	15·34577	15	36	28·520	−16	24	10·62	+0·039	−2·61	R
846	Aug.	15·34577	15	36	28·516	−16	24	10·72			
		18 Melpomene 1967 U.T.									
847	May	31·76593	20	56	17·080	−07	28	24·96	+0·010	−3·89	R
848	May	31·76593	20	56	17·114	−07	28	24·96			
849	July	10·66408	21	00	19·386	−07	42	29·28	+0·024	−3·86	R
850	July	10·66408	21	00	19·411	−07	42	29·44			
851	Aug.	01·58142	20	44	39·610	−10	34	13·76	−0·012	−3·46	R
852	Aug.	01·58142	20	44	39·574	−10	34	12·86			
853	Aug.	08·57269	20	38	24·886	−11	48	50·94	+0·034	−3·29	S
854	Aug.	08·57269	20	38	24·866	−11	48	49·72			
855	Aug.	15·52971	20	32	26·101	−13	07	09·31	−0·028	−3·10	R
856	Aug.	15·52971	20	32	26·135	−13	07	09·55			
857	Aug.	25·50736	20	25	16·723	−14	58	48·40	+0·003	−2·83	S
858	Aug.	25·50736	20	25	16·769	−14	58	48·43			
859	Aug.	28·48958	20	23	37·721	−15	30	44·12	−0·024	−2·75	S
860	Aug.	28·48958	20	23	37·769	−15	30	44·32			
861	Sept.	08·46650	20	20	05·668	−17	17	35·71	+0·006	−2·49	S
862	Sept.	08·46650	20	20	05·616	−17	17	35·89			
863	Sept.	21·42672	20	21	45·480	−18	55	09·45	−0·011	−2·25	R
864	Sept.	21·42672	20	21	45·520	−18	55	09·74			
865	Sept.	28·41552	20	25	18·230	−19	33	11·10	+0·006	−2·15	R
866	Sept.	28·41552	20	25	18·249	−19	33	11·82			
867	Sept.	29·41976	20	25	57·608	−19	37	47·22	+0·028	−2·15	S
868	Sept.	29·41976	20	25	57·572	−19	37	47·54			
		1 Ceres 1968 U.T.									
869	Feb.	28·75243	14	31	03·590	−01	21	59·06	+0·015	−4·69	S
870	Feb.	28·75243	14	31	03·630	−01	21	59·32			
871	April	01·65434	14	21	36·150	+00	25	19·00	+0·010	−4·92	R
872	April	01·65434	14	21	36·178	+00	25	18·65			
873	April	10·63441	14	14	45·566	+00	56	05·28	+0·039	−4·98	S
874	April	10·63441	14	14	45·546	+00	56	04·98			

TABLE I—*continued*

No.			R.A. (1950·0) h	m	s	Dec. (1950·0) °	′	″	Parallax Factors s	″	
		1 Ceres—*continued*									
875	April	22·58229	14	04	20·476	+01	26	08·64	+0·001	−5·05	W
876	April	22·58229	14	04	20·444	+01	26	07·84			
877	April	30·54669	13	57	19·100	+01	35	40·89	−0·026	−5·06	R
878	April	30·54669	13	57	19·103	+01	35	40·55			
879	May	24·48286	13	41	03·136	+01	00	41·82	+0·014	−4·99	S
880	May	24·48286	13	41	03·124	+01	00	41·74			
881	May	31·46697	13	38	31·076	+00	32	50·24	+0·029	−4·93	S
882	May	31·46697	13	38	31·110	+00	32	50·40			
883	June	03·44900	13	37	47·660	+00	18	47·11	+0·001	−4·90	R
884	June	03·44900	13	37	47·646	+00	18	47·36			
885	June	20·40197	13	37	42·156	−01	21	42·88	−0·001	−4·69	W
886	June	20·40197	13	37	42·212	−01	21	43·03			
887	June	24·39981	13	38	38·193	−01	49	41·62	+0·024	−4·53	S
888	June	24·39981	13	38	38·222	−01	49	41·48			
889	July	01·37167	13	41	04·662	−02	41	35·46	−0·009	−4·51	R
890	July	01·37167	13	41	04·622	−02	41	35·09			
891	July	08·35776	13	44	29·280	−03	36	55·11	0·000	−4·39	R
892	July	08·35776	13	44	29·328	−03	36	55·48			
893	July	16·33720	13	49	27·336	−04	43	16·01	−0·008	−4·24	W
894	July	16·33720	13	49	27·333	−04	43	16·26			
		3 Juno 1968 U.T.									
895	April	01·67492	14	46	21·558	−03	22	07·30	+0·021	−4·43	R
896	April	01·67492	14	46	21·606	−03	22	05·96			
897	April	22·59865	14	31	39·937	−00	56	30·40	−0·006	−4·74	W
898	April	22·59865	14	31	39·982	−00	56	30·38			
899	April	30·57250	14	25	16·874	−00	07	56·56	−0·006	−4·85	R
900	April	30·57250	14	25	16·892	−00	07	56·42			
901	June	03·46734	14	03	32·527	+01	39	26·77	+0·002	−5·07	R
902	June	03·46734	14	03	32·532	+01	39	27·49			
		6 Hebe 1968 U.T.									
903	April	22·79511	18	52	44·690	−07	10	14·88	+0·042	−3·93	W
904	April	22·79511	18	52	44·722	−07	10	14·86			
905	April	30·75499	18	56	05·899	−06	38	30·05	−0·022	−4·00	R
906	April	30·75499	18	56	05·939	−06	38	30·05			
907	May	06·75326	18	57	36·864	−06	16	32·01	+0·020	−4·05	S
908	May	06·75326	18	57	36·890	−06	16	32·13			
909	May	28·70402	18	55	03·886	−05	23	34·28	+0·059	−4·17	R
910	May	28·70402	18	55	03·882	−05	23	34·14			
911	May	30·67177	18	54	11·525	−05	21	51·59	−0·022	−4·17	R
912	May	30·67177	18	54	11·493	−05	21	51·86			
913	June	03·66882	18	52	06·194	−05	20	22·48	+0·008	−4·18	S
914	June	03·66882	18	52	06·220	−05	20	21·87			
915	June	19·61214	18	40	06·456	−05	44	10·23	−0·007	−4·12	R
916	June	19·61214	18	40	06·432	−05	44	09·98			
917	June	24·60790	18	35	25·628	−06	02	14·58	+0·032	−4·08	W
918	June	24·60790	18	35	25·643	−06	02	14·22			
919	July	03·57483	18	26	32·540	−06	47	28·81	+0·025	−3·98	S
920	July	03·57483	18	26	32·493	−06	47	28·79			
921	July	15·53367	18	15	02·013	−08	10	16·98	+0·024	−3·79	W
922	July	15·53367	18	15	02·052	−08	10	16·55			
923	July	24·51005	18	07	43·206	−09	25	10·08	+0·042	−3·62	R
924	July	24·51005	18	07	43·242	−09	25	11·00			
925	July	29·48561	18	04	27·434	−10	09	49·46	+0·014	−3·51	S
926	July	29·48561	18	04	27·418	−10	09	49·38			
927	Aug.	09·44627	17	59	45·464	−11	52	05·05	−0·003	−3·27	R
928	Aug.	09·44627	17	59	45·510	−11	52	05·38			
929	Aug.	22·41169	17	59	03·630	−13	53	09·25	+0·001	−2·98	R
930	Aug.	22·41169	17	59	03·624	−13	53	09·92			
931	Aug.	30·41567	18	01	19·662	−15	04	47·07	+0·078	−2·83	S
932	Aug.	30·41567	18	01	19·682	−15	04	47·15			
933	Sept.	11·36921	18	08	20·700	−16	43	49·58	+0·020	−2·56	R
934	Sept.	11·36921	18	08	20·764	−16	43	48·64			

Table I—*continued*

No.			R.A. (1950·0) h	m	s	Dec. (1950·0) °	′	″	Parallax Factors s	″	
		7 Iris 1968 U.T.									
935	April	22·68299	16	21	25·774	−24	41	20·10	+0·021	−1·67	W
936	April	22·68299	16	21	25·750	−24	41	20·00			
937	April	30·64938	16	15	50·691	−24	22	56·66	−0·006	−1·42	R
938	April	30·64938	16	15	50·686	−24	22	57·08			
939	May	20·59368	15	57	09·901	−23	11	42·30	+0·034	−1·60	W
940	May	20·59368	15	57	09·840	−23	11	42·30			
941	May	30·54969	15	47	02·630	−22	26	03·06	+0·002	−1·71	R
942	May	30·54969	15	47	02·550	−22	26	03·14			
943	June	03·53929	15	43	10·086	−22	06	59·80	+0·012	−1·76	S
944	June	03·53929	15	43	10·092	−22	06	59·50			
945	June	20·48362	15	29	29·900	−20	49	29·07	+0·013	−1·96	R
946	June	20·48362	15	29	29·870	−20	49	28·72			
947	June	24·47870	15	27	09·196	−20	33	28·14	+0·038	−1·99	S
948	June	24·47870	15	27	09·203	−20	33	28·02			
949	July	12·41190	15	21	38·552	−19	39	51·58	−0·008	−2·12	R
950	July	12·41190	15	21	38·486	−19	39	51·12			
951	July	16·41015	15	21	32·744	−19	32	27·20	+0·023	−2·14	W
952	July	16·41015	15	21	32·778	−19	32	27·34			
953	July	24·39569	15	22	32·964	−19	22	43·12	+0·022	−2·16	S
954	July	24·39569	15	22	32·989	−19	22	42·79			
955	Aug.	01·37326	15	25	04·420	−19	19	26·46	+0·037	−2·18	W
956	Aug.	01·37326	15	25	04·360	−19	19	25·82			
		39 Laetitia 1968 U.T.									
957	April	30·77887	19	24	37·960	−10	17	42·44	−0·009	−3·67	R
958	April	30·77887	19	24	37·983	−10	17	42·57			
959	May	09·77129	19	27	47·631	−09	45	35·50	+0·037	−3·57	S
960	May	09·77129	19	27	47·684	−09	45	35·00			
961	May	29·69810	19	28	03·710	−08	54	32·11	−0·021	−3·69	R
962	May	29·69810	19	28	03·672	−08	54	32·14			
963	June	19·63763	19	18	13·594	−08	48	18·38	−0·010	−3·70	R
964	June	19·63763	19	18	13·586	−08	48	18·74			
965	June	24·63458	19	14	36·540	−08	55	44·95	+0·031	−3·69	W
966	June	24·63458	19	14	36·539	−08	55	44·72			
967	July	03·59619	19	07	21·450	−09	17	59·82	+0·004	−3·63	S
968	July	03·59619	19	07	21·430	−09	17	59·79			
969	July	15·55860	18	57	09·041	−10	03	49·23	+0·010	−3·53	W
970	July	15·55860	18	57	09·075	−10	03	49·55			
971	July	24·52893	18	50	00·116	−10	47	50·10	+0·010	−3·42	R
972	July	24·52893	18	50	00·082	−10	47	50·82			
973	Aug.	02·48202	18	44	02·635	−11	37	19·26	−0·056	−3·31	R
974	Aug.	02·48202	18	44	02·688	−11	37	19·28			
975	Aug.	22·43637	18	37	18·004	−13	34	18·30	−0·004	−3·03	R
976	Aug.	22·43637	18	37	18·030	−13	34	18·27			
977	Aug.	30·43493	18	37	33·342	−14	19	37·74	+0·060	−2·93	S
978	Aug.	30·43493	18	37	33·250	−14	19	37·92			
979	Sept.	11·39343	18	41	08·698	−15	21	58·04	+0·024	−2·77	R
980	Sept.	11·39343	18	41	08·552	−15	21	58·78			
981	Sept.	16·37527	18	43	42·656	−15	45	26·22	+0·004	−2·71	R
982	Sept.	16·37527	18	43	42·586	−15	45	26·12			
		433 Eros 1968 U.T.									
983	April	01·52752	11	09	20·781	−38	50	58·35	+0·038	+0·80	R
984	April	01·52752	11	09	20·746	−38	50	57·66			
985	April	08·49974	11	06	11·779	−37	19	27·00	+0·012	+0·64	S
986	April	08·49974	11	06	11·710	−37	19	28·00			
987	April	22·47356	11	09	34·680	−33	39	02·45	+0·048	0·00	S
988	April	22·47356	11	09	34·610	−33	39	03·00			
989	April	23·46723	11	10	15·082	−33	22	58·68	+0·032	−0·04	R
990	April	23·46723	11	10	15·004	−33	22	59·95			

TABLE I—*continued*

No.			R.A. (1950·0) h	m	s	Dec. (1950·0) °	′	″	Parallax Factors s	″	
		433 Eros—*continued*									
991	May	03·44830	11	19	38·694	−30	48	10·60	+0·038	−0·44	S
992	May	03·44830	11	19	38·739	−30	48	10·18			
993	May	06·43002	11	23	16·052	−30	05	31·94	−0·007	−0·57	R
994	May	06·43002	11	23	16·000	−30	05	31·84			

TABLE II

No.	Star	Depend.	R.A.	Dec.
813	5521	0·362834	28·785	36·92
	5563	0·357603	39·437	15·08
	5543	0·279563	28·978	41·35
814	5517	0·448661	54·714	33·32
	5547	0·321478	12·152	50·02
	5582	0·229860	25·925	59·53
815	5543	0·345773	28·978	41·35
	5593	0·233701	27·260	11·38
	5547	0·420526	12·152	50·02
816	5534	0·524226	23·194	39·06
	5563	0·249798	39·437	15·08
	5582	0·225976	25·925	59·53
817	5556	0·268040	50·653	41·64
	5615	0·229170	18·482	01·12
	5569	0·502790	18·984	09·92
818	5541	0·257780	28·232	09·69
	5568	0·347107	17·527	10·36
	5597	0·395113	03·052	56·30
819	5556	0·235034	50·653	41·64
	5541	0·246591	28·232	09·69
	5585	0·518375	28·923	29·10
820	5549	0·297354	31·973	32·69
	5597	0·280777	03·052	56·30
	5568	0·421869	17·527	10·36
821	5556	0·342070	50·653	41·64
	5595	0·340074	52·024	39·59
	5541	0·317856	28·232	09·69
822	5534	0·300426	23·194	39·06
	5585	0·361675	28·923	29·10
	5561	0·337899	33·334	40·24
823	5529	0·301096	23·300	42·23
	5540	0·448970	00·007	07·72
	5541	0·249934	28·232	09·69
824	5522	0·333278	34·949	51·66
	5556	0·429128	50·653	41·64
	5534	0·237594	23·195	39·06
825	5504	0·261232	38·540	30·64
	5524	0·404840	11·046	33·86
	5529	0·333928	23·300	42·23
826	5499	0·379692	50·902	27·11
	5536	0·246502	37·839	01·17
	5517	0·373806	54·714	33·33
827	5488	0·468630	02·275	28·33
	5503	0·208141	33·516	55·65
	5507	0·323229	55·260	37·83
828	5491	0·485070	48·225	32·32
	5494	0·151433	05·102	59·65
	5505	0·363497	37·942	49·09
829	5444	0·525642	08·378	25·95
	5468	0·231108	48·883	26·14
	5475	0·243250	18·301	54·94
830	5441	0·426363	16·851	08·77
	5454	0·303059	14·412	57·07
	5488	0·270578	02·275	28·33
831	5395	0·387552	56·650	31·38
	5411	0·180678	33·916	00·88
	5426	0·431770	35·181	04·54
832	5394	0·331762	46·967	19·02
	5399	0·277458	28·039	46·99
	5433	0·390780	03·093	01·98
833	5371	0·318654	11·986	52·78
	5394	0·338596	46·976	19·02
	5403	0·342749	56·994	31·16
834	5362	0·356620	34·219	45·70
	5399	0·240794	28·039	46·99
	5409	0·402586	15·282	03·11
835	5285	0·269911	29·781	04·37
	5315	0·215570	31·498	17·83
	5312	0·514519	37·015	59·47
836	5281	0·404270	22·834	14·23
	5331	0·251602	40·154	44·65
	5306	0·344128	58·775	11·40
837	5295	0·335904	56·201	06·20
	5313	0·405987	38·041	03·82
	5320	0·258110	56·328	00·22
838	5292	0·404903	22·652	35·25
	5315	0·332500	58·797	11·37
	5326	0·262597	02·518	38·70
839	5302	0·220162	08·480	12·54
	5312	0·378813	37·015	59·46
	5326	0·401025	02·518	38·71
840	5292	0·267828	22·653	35·25
	5310	0·347030	28·441	57·38
	5331	0·385142	40·154	44·65
841	5321	0·345928	06·706	05·27
	5326	0·338082	02·518	38·70
	5356	0·315990	23·778	40·80
842	5320	0·273410	56·327	00·23
	5325	0·294460	01·044	12·77
	5349	0·432130	39·406	34·23
843	5646	0·402986	14·162	25·53
	5677	0·219381	50·024	44·57
	5680	0·377633	29·436	49·74
844	5381	0·379346	18·082	00·39
	5670	0·385071	17·542	25·66
	5685	0·235583	08·963	35·40
845	5713	0·252844	07·044	23·47
	5733	0·414797	10·381	31·34
	5746	0·332359	24·680	22·77
846	5719	0·343150	22·690	40·17
	5723	0·375746	55·591	07·44
	5753	0·281104	06·748	43·57

Table II—*continued*

No.	Star	Depend.	R.A.	Dec.	No.	Star	Depend.	R.A.	Dec.
847	7505	0·337836	26·657	31·88	869	3755	0·372320	20·898	29·62
	7514	0·210432	11·612	35·72		3759	0·280362	11·099	17·89
	7540	0·451732	54·978	34·18		3767	0·347318	51·903	06·54
848	7504	0·332402	08·694	58·12	870	3751	0·459731	40·585	36·58
	7530	0·186468	25·597	04·01		3762	0·219900	05·911	49·11
	7536	0·481130	00·857	27·20		3772	0·320369	38·229	04·14
849	7539	0·221648	13·152	58·63	871	3720	0·229014	55·491	39·18
	7544	0·523231	31·064	32·33		3735	0·477335	11·979	49·89
	7551	0·255121	45·067	53·27		4954	0·293651	30·039	37·73
850	7527	0·303636	46·753	15·56	872	3717	0·338688	53·245	56·34
	7550	0·345096	28·683	48·49		3739	0·302758	28·980	01·82
	7554	0·351267	15·041	57·81		4958	0·358554	28·238	01·66
851	7355	0·435764	54·173	49·92	873	4910	0·313044	16·764	11·05
	7356	0·273850	56·374	44·43		4919	0·420399	35·928	02·85
	7374	0·290386	28·550	35·70		4931	0·266557	55·508	39·35
852	7342	0·272108	53·572	32·64	874	4902	0·377086	08·638	39·99
	7362	0·431200	25·791	02·22		4926	0·270494	01·571	27·73
	7372	0·296692	04·694	50·05		3717	0·352419	53·245	56·34
853	7295	0·220344	32·830	44·74	875	4871	0·321511	33·444	08·23
	7321	0·513860	58·369	04·80		4873	0·464002	44·467	45·41
	7328	0·265796	32·697	22·00		4881	0·214487	48·872	37·70
854	7310	0·473984	44·220	57·11	876	4861	0·244082	17·506	56·91
	7322	0·231504	01·836	27·66		4875	0·481652	11·086	43·69
	7330	0·294512	37·628	56·61		4884	0·274266	19·668	45·52
855	7268	0·292908	26·320	52·26	877	4822	0·291314	15·515	50·66
	7269	0·373613	32·635	06·57		4839	0·310046	42·165	13·03
	7292	0·333478	18·461	52·12		4847	0·398640	12·506	55·97
856	7256	0·381122	45·165	39·88	878	4820	0·292875	47·527	31·88
	7277	0·308756	34·210	16·39		4846	0·372263	05·098	32·59
	7303	0·310122	35·924	21·19		4849	0·334862	18·838	47·73
857	7696	0·379695	16·288	01·67	879	3617	0·242315	47·941	46·90
	7705	0·395216	41·953	03·40		4782	0·284572	47·218	35·58
	7709	0·225089	14·429	38·10		4790	0·473113	54·161	44·64
858	7689	0·544647	29·369	18·67	880	4768	0·433148	33·491	45·73
	7703	0·198112	29·478	22·94		4787	0·175497	31·232	36·03
	7722	0·257241	54·223	14·34		3637	0·391355	22·041	13·70
859	7668	0·284275	22·996	07·05	881	3607	0·326654	25·511	22·13
	7696	0·481317	16·288	01·68		4769	0·285174	01·344	30·20
	7708	0·234408	14·424	46·64		4790	0·388172	54·161	44·64
860	7672	0·338857	15·469	51·80	882	3612	0·314368	56·554	57·35
	7688	0·329132	26·238	24·48		4768	0·333407	33·491	45·73
	7709	0·332012	14·429	38·10		4789	0·352225	33·922	51·45
861	7641	0·351958	16·780	19·09	883	3612	0·381416	56·554	57·35
	7664	0·336796	43·239	54·72		3632	0·256947	45·955	29·81
	7692	0·311246	40·909	31·14		4768	0·361637	33·491	45·73
862	8716	0·343064	01·528	53·73	884	3618	0·434692	50·406	48·48
	7660	0·393358	52·990	22·83		3634	0·186853	54·125	44·16
	7700	0·263578	35·012	59·31		4769	0·378455	01·343	30·20
863	8720	0·265192	13·266	36·21	885	3610	0·282714	09·629	22·05
	8751	0·273096	11·425	48·61		3624	0·336633	38·275	07·31
	8762	0·461713	31·869	53·96		3627	0·380652	23·434	24·12
864	8723	0·277731	39·910	06·48	886	3614	0·380901	18·545	08·33
	8750	0·287292	07·534	37·99		3618	0·249447	50·405	48·48
	8761	0·434977	29·446	59·34		3628	0·369652	25·672	19·26
865	8761	0·445130	29·447	59·34	887	3609	0·343210	59·668	42·59
	8796	0·382459	54·740	02·78		3627	0·455987	23·434	24·12
	8766	0·172411	12·374	01·21		4927	0·200803	35·146	53·40
866	8759	0·353126	02·768	04·79	888	3614	0·393083	18·545	08·33
	8800	0·342912	28·247	05·56		3626	0·349484	19·458	00·73
	8770	0·303962	21·908	49·88		3628	0·257434	25·672	19·26
867	8761	0·316142	29·447	59·35	889	3624	0·356954	38·276	07·31
	8799	0·418963	08·472	47·65		4919	0·395897	04·107	25·81
	8776	0·264895	27·195	41·00		4945	0·247148	03·728	30·59
868	8751	0·251302	11·426	48·61	890	4913	0·215240	07·537	36·44
	8787	0·404961	51·639	31·38		4941	0·201653	20·151	45·33
	8794	0·343737	39·394	19·72		3626	0·583106	19·458	00·73

Table II—*continued*

No.	Star	Depend.	R.A.	Dec.	No.	Star	Depend.	R.A.	Dec.
891	4925	0·266509	09·688	57·91	913	6333	0·363812	51·638	38·25
	4935	0·288141	11·556	00·77		6403	0·353674	32·303	26·86
	4946	0·445350	04·273	22·60		6453	0·282515	15·660	42·86
892	4919	0·306863	04·107	25·81	914	6366	0·585622	20·991	32·13
	4943	0·378822	49·920	36·11		6370	0·251318	44·497	55·17
	4947	0·314315	12·656	49·31		6400	0·163060	21·984	02·32
893	4948	0·279699	18·252	30·74	915	6261	0·384989	26·309	14·21
	4956	0·398107	45·238	49·74		6278	0·217461	44·185	32·15
	4973	0·322194	03·495	25·50		6320	0·397550	53·837	00·52
894	4943	0·432322	49·921	36·13	916	6253	0·371178	23·053	29·11
	4969	0·285041	06·444	46·62		6299	0·311820	37·277	30·64
	4970	0·282637	19·653	53·38		6313	0·317002	59·547	19·12
895	5211	0·300332	06·324	36·29	917	6217	0·384338	39·516	12·71
	5213	0·324327	35·988	32·73		6273	0·218476	55·972	18·64
	5230	0·375341	40·986	50·53		6264	0·397186	06·818	00·10
896	5205	0·221190	59·773	25·43	918	6231	0·230728	11·979	54·39
	5218	0·419780	32·130	41·96		6236	0·473518	30·373	51·57
	5224	0·359030	50·458	00·92		6263	0·295754	51·515	18·16
897	3758	0·273497	08·709	27·26	919	6186	0·273048	30·577	01·37
	3761	0·513562	33·804	49·02		6200	0·284996	25·891	01·87
	3767	0·212941	51·903	06·55		6209	0·441956	07·748	05·17
898	3756	0·266327	37·660	59·12	920	6187	0·384220	32·379	17·68
	3757	0·432826	28·128	09·09		6206	0·393322	08·605	18·84
	3775	0·300847	31·029	28·54		6217	0·222458	39·516	12·71
899	3734	0·336538	01·966	28·99	921	6126	0·279652	40·419	24·61
	3740	0·246404	03·233	42·75		6135	0·262563	27·412	16·02
	3756	0·417058	37·660	59·12		6155	0·457785	25·137	19·98
900	3737	0·295508	42·500	52·04	922	6124	0·373234	35·570	41·03
	3744	0·540264	12·626	57·40		6148	0·303088	59·212	20·20
	3758	0·164228	08·709	27·27		6156	0·323678	06·458	12·66
901	4857	0·321392	37·938	24·74	923	6088	0·473122	26·021	58·50
	4868	0·404718	22·895	18·49		6126	0·257674	40·419	24·60
	4883	0·273890	11·664	58·84		6208	0·269204	13·355	32·60
902	4853	0·228687	42·849	52·10	924	6102	0·242710	51·778	38·12
	4876	0·442408	20·848	27·61		6108	0·260480	56·790	17·42
	4877	0·328904	07·236	41·62		6114	0·496810	02·068	34·48
903	6405	0·326368	32·226	50·85	925	6088	0·176276	26·021	58·50
	6455	0·282994	22·904	51·74		6102	0·422769	51·777	38·12
	6472	0·390638	57·837	06·01		6172	0·400955	51·810	27·85
904	6414	0·281922	20·916	26·17	926	6145	0·352331	38·436	48·86
	6449	0·498119	02·087	40·78		6181	0·280126	46·693	55·40
	6473	0·219959	09·694	10·81		6112	0·367543	18·347	56·99
905	6463	0·297229	07·642	25·42	927	6118	0·412670	52·495	14·49
	6475	0·414072	26·756	46·47		6152	0·218869	53·908	16·42
	6516	0·288699	03·769	10·29		6167	0·368461	25·446	30·90
906	6449	0·236260	02·087	40·78	928	6135	0·163875	42·702	05·99
	6493	0·317849	56·934	31·66		6147	0·226630	52·668	56·87
	6494	0·445891	06·997	37·70		6148	0·609495	59·717	39·91
907	6475	0·349096	26·756	46·47	929	6125	0·304764	57·596	19·53
	6516	0·377050	03·769	10·28		6163	0·324036	11·920	51·70
	6425	0·273854	23·107	35·45		6477	0·371200	10·054	57·16
908	6484	0·351540	20·030	08·51	930	6475	0·362887	44·908	52·07
	6518	0·399175	14·976	16·46		6513	0·255351	04·795	11·21
	6412	0·249286	48·162	08·29		6140	0·381762	14·526	47·53
909	6375	0·267324	52·260	29·41	931	6490	0·347451	58·080	54·54
	6403	0·373412	32·303	26·86		6492	0·238102	06·944	30·32
	6493	0·359263	56·934	31·66		6532	0·414448	34·460	44·61
910	6379	0·457412	42·008	20·85	932	6474	0·300732	39·416	54·03
	6429	0·264680	44·907	55·74		6512	0·281830	04·116	01·92
	6475	0·277909	26·756	46·47		6527	0·417438	11·101	38·35
911	6366	0·406682	20·991	32·13	933	6550	0·213884	11·244	47·12
	6403	0·340448	32·303	26·86		6562	0·284246	12·187	58·70
	6493	0·252870	56·935	31·66		6597	0·501870	54·600	23·01
912	6373	0·271165	46·975	47·59	934	6529	0·226692	18·867	49·76
	6375	0·290456	52·260	29·41		6588	0·411246	19·512	22·20
	6419	0·438379	13·184	43·41		6595	0·362062	45·472	15·09

Table II—*continued*

No.	Star	Depend.	R.A.	Dec.	No.	Star	Depend.	R.A.	Dec.
935	11451	0·397613	18·789	47·29	957	6735	0·324965	48·564	20·77
	11460	0·380764	00·255	59·65		6783	0·340877	07·982	56·80
	11490	0·221623	57·438	37·37		6829	0·334158	56·256	47·18
936	11449	0·244110	53·934	22·96	958	6769	0·296208	09·385	34·60
	11469	0·235264	56·553	27·57		6813	0·317583	03·018	05·07
	11471	0·520626	22·819	07·97		6760	0·386209	18·881	41·96
937	11415	0·432909	30·453	54·13	959	6797	0·247491	50·727	18·94
	11430	0·224483	34·071	07·47		6848	0·317173	34·562	22·73
	11433	0·342608	03·706	46·80		6786	0·435336	10·218	30·61
938	11400	0·321692	51·608	57·27	960	6760	0·314000	18·881	41·96
	11437	0·277014	10·307	02·88		6798	0·399181	07·692	46·63
	11440	0·401294	19·594	45·70		6839	0·286820	39·351	04·58
939	11237	0·313002	37·228	53·33	961	6763	0·227899	28·888	55·52
	11247	0·416973	45·307	29·65		6784	0·314836	53·001	29·53
	11272	0·270025	35·396	30·16		6801	0·457265	28·259	30·43
940	11243	0·549268	25·700	33·34	962	6760	0·257816	18·881	41·96
	11246	0·311978	39·348	14·87		6772	0·325087	46·705	57·21
	11292	0·138754	12·679	55·71		6808	0·417096	45·513	20·83
941	11149	0·232179	04·573	23·93	963	6678	0·373236	34·178	20·23
	11167	0·384622	28·121	31·25		6693	0·324260	58·142	54·47
	6538	0·383199	11·991	58·26		6719	0·302504	32·847	27·79
942	11115	0·445430	14·296	04·63	964	6667	0·243414	15·118	53·26
	11194	0·227503	16·637	19·07		6687	0·388576	18·974	31·15
	6564	0·327067	37·035	19·15		6722	0·368010	09·096	54·75
943	6495	0·244812	14·677	25·56	965	6648	0·260750	03·059	16·11
	6528	0·521091	25·844	47·87		6657	0·365332	42·857	46·06
	11115	0·234097	14·296	04·63		6678	0·373918	34·178	20·23
944	6506	0·512158	24·629	15·26	966	6647	0·424937	53·811	43·47
	6526	0·243542	59·691	53·88		6661	0·303704	34·403	39·28
	11139	0·244300	01·665	41·29		6688	0·271360	19·750	07·57
945	6398	0·205401	28·585	12·58	967	6577	0·468976	27·413	59·04
	6403	0·309974	28·115	33·42		6600	0·227732	15·005	36·84
	6432	0·484625	04·702	31·60		6616	0·303292	37·838	20·72
946	6393	0·339866	32·403	08·67	968	6563	0·372683	55·105	57·96
	6451	0·278260	15·417	10·40		6630	0·220408	43·109	09·13
	6415	0·381874	32·558	47·17		6650	0·406909	41·290	32·24
947	6386	0·261658	12·804	01·84	969	6529	0·218512	50·422	01·17
	6398	0·325960	28·586	12·57		6544	0·335624	40·807	59·52
	6415	0·412382	32·557	47·17		6510	0·445863	38·058	43·94
948	6391	0·323702	24·909	18·99	970	6525	0·230792	14·573	48·56
	6422	0·318282	10·848	58·89		6585	0·202910	52·499	33·52
	6396	0·358016	01·764	11·79		6492	0·566297	00·175	27·99
949	6340	0·182730	35·145	31·95	971	6458	0·386291	28·956	01·82
	6371	0·397562	48·236	49·65		6505	0·209090	41·981	18·21
	6381	0·419708	41·822	27·02		6512	0·404619	29·195	55·88
950	6351	0·305714	44·144	18·44	972	6477	0·215078	17·958	35·83
	6360	0·366555	08·871	01·21		6478	0·343428	21·451	39·58
	6396	0·327731	01·765	11·79		6509	0·441494	06·539	02·59
951	6351	0·274644	41·144	18·44	973	6414	0·240288	44·694	16·19
	6360	0·363085	08·871	01·21		6445	0·328216	56·803	07·67
	6389	0·362271	04·589	12·39		6447	0·431496	11·764	15·09
952	6340	0·171942	35·145	31·95	974	6419	0·370083	37·833	44·67
	6371	0·489181	48·236	49·65		6434	0·346008	08·018	45·67
	6381	0·338877	41·822	27·02		6477	0·283909	17·958	35·83
953	6363	0·309362	49·164	36·86	975	6370	0·376868	10·463	40·58
	6371	0·369218	48·236	49·65		6424	0·254714	18·159	04·49
	6389	0·321420	04·589	12·39		6872	0·368418	03·767	13·32
954	6361	0·472806	19·284	37·21	976	6828	0·263428	42·361	30·22
	6380	0·281997	15·784	52·11		6915	0·218818	49·752	22·77
	9396	0·245197	01·765	11·79		6400	0·517753	48·181	04·07
955	6370	0·370790	37·507	15·42	977	6851	0·342576	32·765	34·24
	6387	0·269874	41·850	51·23		6900	0·299008	30·348	53·66
	6410	0·359337	54·643	27·42		6402	0·358417	57·927	52·34
956	6363	0·259726	49·164	36·86	978	6861	0·439100	03·129	20·03
	6395	0·323772	51·688	02·98		6862	0·207960	11·092	04·82
	6400	0·416502	06·623	51·19		6897	0·352940	13·994	27·58

TABLE II—*continued*

No.	Star	Depend.	R.A.	Dec.	No.	Star	Depend.	R.A.	Dec.
979	6878	0·419632	38·779	03·89	987	5486	0·501998	57·08	15·9
	6900	0·319516	30·348	53·66		5506	0·166920	32·43	48·3
	6936	0·260852	55·802	02·59		5530	0·331082	03·81	08·8
980	6865	0·427652	50·016	10·05	988	5465	0·224590	03·55	16·8
	6923	0·287646	58·717	14·61		5516	0·475334	29·10	03·8
	6926	0·284702	45·677	24·11		5518	0·300075	46·51	13·5
981	6901	0·372775	31·795	45·72	989	5486	0·346580	57·08	15·9
	6932	0·301345	14·628	32·71		5518	0·300992	46·51	13·5
	6936	0·325880	55·802	02·59		5530	0·352428	03·81	08·8
982	6878	0·353606	38·780	03·89	990	5494	0·389483	38·96	12·0
	6923	0·279205	58·717	14·61		5496	0·263760	46·75	30·5
	6957	0·367189	23·103	16·03		5537	0·346757	09·59	26·7
983	5192	0·246012	20·04	10·8	991	5563	0·294274	42·564	15·78
	5236	0·420334	20·19	43·2		5622	0·408712	11·397	56·37
	5241	0·333654	04·14	10·9		5624	0·297014	24·386	23·61
984	5209	0·358582	31·11	20·2	992	5566	0·340738	51·203	36·99
	5229	0·310074	26·75	52·9		5598	0·304058	23·574	28·25
	5242	0·331344	13·11	20·5		5641	0·355204	30·850	04·44
985	5177	0·422606	30·63	32·0	993	5615	0·310369	32·697	11·42
	5210	0·261198	42·55	59·1		5680	0·337116	03·234	13·28
	5220	0·316196	30·13	07·0		7517	0·352515	02·620	03·51
986	5182	0·321712	56·67	40·4	994	5622	0·306539	11·397	56·37
	5195	0·329581	30·19	11·0		5641	0·243516	30·850	04·44
	5225	0·348706	55·44	28·4		7534	0·449945	32·455	33·97

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Occultations Observed at Sydney Observatory during 1967-68

K. P. Sims

The following observations of occultations were made at Sydney Observatory with the 11½-inch telescope. A tapping key was used to record the times on a chronograph. The reduction elements were computed by the method given in the occultation Supplement to the *Nautical Almanac* for 1938 and the reduction completed by the method given there. Since the observed times were in terms of coordinated time (UTC), a correction which was derived from *Mount Stromlo Observatory Bulletins A* was applied to the 1967 observations to convert them to universal time (UT2). For 1968 the corrections to the observed times in UTC were derived from *Bureau International De L'Heure Circulaire D*. In 1967 a correction of +0·01028h (=37 seconds) was applied to the time in UT2 to convert it to ephemeris time with which *The Astronomical Ephemeris for 1967* was entered to obtain the position and parallax of the Moon. In 1968 this correction was +0·01056h (=38 seconds). The apparent places of the stars of the 1967–68 occultations were provided by H.M. Nautical Almanac Office.

Table I gives the observational material. The serial numbers follow on from those of the previous report (Sims, 1967). The observers were W. H. Robertson (R), K. P. Sims (S) and H. W. Wood (W). Except for occultations 497, 498 and 525 which were reappearances at the dark and bright limbs, the phase observed was disappearance at the dark limb. Table II gives the results of the reductions which were carried out in duplicate. The Z.C. numbers given are those of the *Catalog* of 3539 *Zodiacal Stars for Equinox* 1950·0 (Robertson, 1940).

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Robertson, A. J., 1940. *Astronomical Papers of the American Ephemeris,* Vol. X, Part II.

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Table I

Serial No.	Z.C. No.	Mag.	Date	U.T.2	UT2–UTC	Observer
493	0598	5·7	1967 Mar. 17	9 20 49·34	+0·03	R
494	1416	7·2	1967 Apr. 19	12 39 53·06	+0·03	R
495	1647	6·7	1967 Apr. 21	9 31 41·55	+0·03	S
496	2025	6·8	1967 Apr. 24	10 50 07·86	+0·03	R
497	2480	5·3	1967 Apr. 27	14 34 37·23	+0·03	S
498	2479	5·3	1967 Apr. 27	14 34 42·03	+0·03	S
499	1733	5·2	1967 May 19	13 21 10·43	+0·04	W
500	1544	5·7	1967 July 11	7 55 53·83	+0·04	W
501	2424	6·9	1967 July 18	8 37 50·63	+0·04	R
502	2427	7·1	1967 July 18	9 53 03·67	+0·04	R
503	1134	5·0	1968 Apr. 6	9 01 56·53	+0·02	W
504	1137	5·1	1968 Apr. 6	9 22 04·62	+0·02	W
505	1139	8·0	1968 Apr. 6	9 54 33·69	+0·02	W
506	1740	7·6	1968 June 5	10 04 42·58	+0·02	R
507	1746	7·1	1968 June 5	12 59 27·27	+0·02	S
508	1865	7·2	1968 June 6	13 16 16·57	+0·02	S

TABLE I—*Continued*

Serial No.	Z.C. No.	Mag.	Date	U.T.2	UT2–UTC	Observer
509	1966	8·1	1968 June 7	8 15 31·83	+0·02	R
510	1596	7·0	1968 July 1	7 46 58·92	+0·03	R
511	1603	7·1	1968 July 1	10 09 26·62	+0·03	R
512	1824	7·8	1968 July 3	12 51 13·28	+0·03	S
513	1911	7·1	1968 July 31	11 32 36·37	+0·03	R
514	2031	8·7	1968 Aug. 1	12 26 18·67	+0·03	S
515	2153	8·4	1968 Aug. 2	12 02 32·34	+0·03	R
516	2289	8·1	1968 Aug. 3	8 26 52·74	+0·03	W
517	2299	6·4	1968 Aug. 3	11 02 19·10	+0·03	W
518	2449	7·5	1968 Aug. 4	8 18 19·20	+0·03	W
519	2470	6·1	1968 Aug. 4	13 43 09·24	+0·03	W
520	2617	4·7	1968 Aug. 5	7 58 55·13	+0·03	W
521	2644	6·3	1968 Aug. 5	12 35 48·96	+0·03	W
522	2257	6·7	1968 Aug. 30	11 02 43·83	+0·02	S
523	2366	1·2	1968 Sept. 27	8 30 48·73	+0·01	S
524	2373	6·2	1968 Sept. 27	9 36 23·26	+0·01	S
525	2366	1·2	1968 Sept. 27	9 36 51·19	+0·01	S
526	2536	7·4	1968 Sept. 28	11 05 20·10	+0·01	W
527	3180	8·2	1968 Oct. 2	12 48 38·33	+0·01	R
528	2489	8·5	1968 Oct. 25	10 10 37·83	+0·02	S
529	3391	6·8	1968 Oct. 31	9 48 09·79	+0·02	W
530	3389	7·6	1968 Oct. 31	9 52 36·95	+0·02	W
531	3388	5·6	1968 Oct. 31	10 03 41·93	+0·02	W
532	3394	7·4	1968 Oct. 31	10 56 44·22	+0·02	W
533	2583	5·8	1968 Nov. 22	9 22 26·76	+0·02	S
534	3240	6·6	1968 Nov. 26	12 40 07·23	+0·02	R

TABLE II

Serial No.	Lunation No.	p	q	p^2	pq	q^2	$\Delta\sigma$	$p\Delta\sigma$	$q\Delta\sigma$	Coefficient of $\Delta\alpha$	Coefficient of $\Delta\delta$
493	547	+64	+77	41	+49	59	−0·5	−0·3	−0·4	+5·6	+0·91
494	548	+67	−74	45	−50	55	0·0	0·0	0·0	+5·3	−0·93
495	548	+80	−60	64	−48	36	+0·6	+0·5	−0·4	+6·7	−0·89
496	548	+90	+43	81	+39	19	−1·1	−1·0	−0·5	+14·7	0·00
497	548	−70	−71	49	+50	51	+0·8	−0·6	−0·6	−10·7	−0·60
498	548	−71	−71	50	+50	50	−0·2	+0·1	+0·1	−10·8	−0·59
499	549	+74	−67	55	−50	45	−0·3	−0·2	+0·2	+5·1	−0·94
500	551	+77	−63	60	−49	40	+0·5	+0·4	−0·3	+6·4	−0·90
501	551	+98	−18	97	−18	3	+0·1	+0·1	0·0	+12·6	−0·36
502	551	+94	−34	88	−32	12	−0·3	−0·3	+0·1	+11·6	−0·51
503	560	+89	+46	79	+41	21	−1·4	−1·2	−0·6	+12·5	+0·33
504	560	+98	−20	96	−20	4	−0·5	−0·5	+0·1	+12·4	−0·34
505	560	+100	+ 2	100	+2	0	+1·4	+1·4	0·0	+13·1	−0·14
506	562	+87	−49	76	−43	24	+0·5	+0·4	−0·2	+8·1	−0·84
507	562	+74	−68	54	−50	46	+1·5	+1·1	−1·0	+4·9	−0·95
508	562	+96	−28	92	−27	8	−2·0	−1·9	+0·6	+10·7	−0·70
509	562	+59	−81	35	−48	65	+0·8	+0·5	−0·6	+2·7	−0·98
510	563	+97	+25	94	+24	6	−0·7	−0·7	−0·2	+14·4	−0·22
511	563	+97	−23	95	−22	5	−1·5	−1·5	+0·3	+11·2	−0·65
512	563	+84	+54	71	+45	29	+0·6	+0·5	+0·3	+15·0	+0·08
513	564	+47	+88	22	+41	78	−0·1	0·0	−0·1	+12·1	+0·58
514	564	+97	+25	94	+24	6	+0·9	+0·9	+0·2	+14·3	−0·17
515	564	+81	+59	65	+48	35	−0·9	−0·7	−0·5	+13·5	+0·28
516	564	+76	+65	58	+49	42	−0·8	−0·6	−0·5	+12·3	+0·43
517	564	+100	+6	100	+6	0	+0·1	+0·1	0·0	+13·4	−0·19
518	564	+86	+51	74	+44	26	−0·3	−0·3	−0·2	+12·4	+0·38
519	564	+52	−85	27	−44	73	+1·0	+0·5	−0·8	+5·5	−0·91

TABLE II—*continued*

Serial No.	Luna- tion No.	p	q	q^2	pq	q^2	$\Delta\sigma$	$p\Delta\sigma$	$q\Delta\sigma$	Coefficient of	
										$\Delta\alpha$	$\Delta\delta$
520	564	+45	−89	20	−40	80	+0·7	+0·3	−0·6	+5·8	−0·90
521	564	+97	+26	93	+25	7	−0·4	−0·4	−0·1	+13·2	+0·03
522	565	+90	+43	81	+39	19	−0·6	−0·5	−0·3	+13·5	+0·16
523	566	+93	−37	86	−34	14	−0·3	−0·3	+0·1	+11·2	−0·55
524	566	+81	−58	66	−47	34	+2·0	+1·6	−1·2	+9·2	−0·73
525	566	−86	−52	73	+44	27	−0·1	+0·1	+0·1	−12·6	−0·34
526	566	+72	−70	51	−50	49	+0·6	+0·4	−0·4	+8·9	−0·74
527	566	+100	−8	99	−8	1	0·0	0·0	0·0	+13·6	+0·31
528	567	+98	−19	96	−19	4	+0·1	+0·1	0·0	+12·8	−0·28
529	567	+99	−16	97	−16	3	−0·2	−0·2	0·0	+14·1	+0·32
530	567	+73	+68	53	+50	47	−0·2	−0·1	−0·1	+4·9	+0·94
531	567	+45	+89	20	+40	80	−0·2	−0·1	−0·2	−0·1	+1·00
532	567	+94	−33	89	−31	11	−0·7	−0·7	+0·2	+14·7	+0·14
533	568	+99	−12	99	−12	1	+0·1	+0·1	0·0	+13·1	−0·14
534	568	+40	−92	16	−37	84	+2·4	+1·0	−2·2	+10·9	−0·66

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A Note on a Kinematical Derivation of Lorentz Transformations

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1. There is a close analogy between the assumptions of Milne's Kinematical Relativity (Milne, 1948) and the k-calculus with the help of which Bondi (1964) derives Lorentz transformations. In both accounts a rigid measuring rod is replaced by measurements of distance carried out by means of light signals. This is particularly appropriate when " distant " events are being observed since a " measuring rod " can, at best, be transported only to the nearest celestial bodies.

Kinematics based on signalling techniques will be called " Radar Physics ". The purpose of this note is to analyse the axioms needed to derive the velocity formula of Special Relativity from which the Lorentz transformations can be easily obtained. All observers (and all observable events) of Radar Physics are assumed to be equipped with a signal-sending device, a mirror capable of reflecting signals instantaneously, and with a clock. It is also necessary to assume that an observer can measure local velocities ; that is, that he can determine relative to himself, the speed of any signal he may send or receive. Likewise, he must be able to measure (again relative to himself) the speed of any observer who passes close to himself (coincides instantaneously at a given point in space).

Two observers, O and O′, situated at different points in space, can easily determine whether they are at rest relative to each other, or not. In fact, let t_0 and t_1 be the times of emission of consecutive signals as recorded by O, and let t_1 and t_2 respectively be the times when he receives these signals back, after their reflection by O′. If

$$t_1-t_0=t_2-t_1, \quad \ldots\ldots\ldots \ (1)$$

O′ is said to be at rest relative to O, even if the velocity (according to O) of the reflected signal should differ from that of the emitted one. We must assume, however, that there is no fluctuation in the direction of their relative motion, if any. By repeating the above experiment several times in succession, O can also discover whether O′ is in a state of uniform motion relative to himself.

To simplify the analysis, let us assume that an observer always sends and receives signals with the same speed c. He cannot have any knowledge of what happens to the signal in transit. Hence he is constrained to define distances as if the transit speed of his signals were the same as measured locally. The relativistic principle of constancy of the velocity of light becomes then a purely local concept.

2. Let O and O′ coincide initially in space. At that instant they can synchronize their clocks to read

$$t_0=t'_0=0.$$

Let us suppose also that O finds O′ moving with a speed

$$v=cV, \text{ say},$$

so that V is dimensionless. Furthermore, let O and O′ observe a distant event E which remains, for the sake of simplicity, in their mutual line of sight (so that O, O′ and E are collinear in a flat space-time).

If a signal sent by O at $t_0=0$ is reflected by E at t_A (on E's clock ; t_A is not O-observable), and received by O again at t_1, the distance x_A of E as calculated by O, is

$$x_A=ct_A=c(t_1-t_A). \quad \ldots\ldots\ldots \ (2)$$

Hence

$$t_A=\tfrac{1}{2}t_1, \ x_A=\frac{c}{2}t_1.$$

O then repeats the experiment with initial and final time readings t_1 and t_2 respectively, to get, say

$$x_B=\frac{c}{2}(t_2-t_1), \quad t_B=\tfrac{1}{2}(t_2+t_1). \ \ldots\ldots \ (3)$$

In this case, O would conclude that in the course of the observations E moved from A to B with an average speed

$$u=\frac{x_B-x_A}{t_B-t_A}=c\left(1-2\frac{t_1}{t_2}\right). \quad \ldots\ldots (4)$$

In a similar way O′ obtains for the " uniform speed " of E relative to himself

$$u'=c\left(1-2\frac{t_1'}{t_2'}\right). \quad \ldots\ldots\ldots (5)$$

Let

$$k=\frac{t_2}{t_1}, \quad k'=\frac{t_2'}{t_1'}. \quad \ldots\ldots\ldots (6)$$

A transformation law between u' and u (that is, the addition formula for velocities) corresponds, therefore, to a relation between k and k'.

3. Let us suppose that this transformation is of the form

$$k'=f(V)k+g(V), \quad \ldots\ldots\ldots (7)$$

where f and g are at most bilinear functions of V, for all conceivable cases of uniform relative motion of O, O′ and E. When O and O′ read, on their respective clocks,

$$t_1=t_2, \quad t_1'=t_2',$$

the event E coincides with them initially. Hence

$$f(V)+g(V)=1, \text{ for all } V. \quad \ldots. (8)$$

If O and O′ travel together so that their clock readings remain the same, we have

$$f(0)=1 \text{ (that is, } g(0)=0). \quad .. (9)$$

Next, suppose that O′ travels with the signal so that he is unable to communicate with O except by reversing his velocity with the consequences familiar from the discussion of the " clock paradox " of Special Relativity. In other words, we have $k'=1$ when $V=1$, or

$$f(1)=0 \text{ (or } g(1)=1). \quad \ldots. (10)$$

Finally, let O′ regard himself at rest, so that the relative velocity of O and O′ is reversed (hitherto we have been viewing the situation as it appears to O). We obtain

$$k=f(-V)k'+g(-V).$$

By comparison with (7), we have

$$g(-V)=-\frac{g(V)}{f(V)}$$

and

$$f(-V)f(V)=1. \quad \ldots\ldots\ldots\ldots (11)$$

The conditions (8)–(11) are sufficient to determine f and g uniquely. Indeed

$$f(V)=\frac{1-V}{1+V} \text{ and } g(V)=\frac{2V}{1+V}. \quad .. (12)$$

or

$$1-\frac{2}{k'}=\frac{1-\frac{2}{k}-V}{1-V\left(1-\frac{2}{k}\right)}. \quad \ldots. (13)$$

4. By equations (4), (5) and (6), (13) becomes Einstein's formula for the addition of velocities:

$$u'=\frac{u-v}{1-\frac{uv}{c^2}}. \quad \ldots\ldots\ldots (14)$$

Special Lorentz transformations follow in the usual way providing we assume equivalence of the observers O and O′. For example, it is sufficient to require that O's clock should go faster than that of O′ if the former regards himself as being at rest and conversely. It is clear that the clocks of O and of O′ must register differently in any case.

It is harder to interpret the assumption involved in writing down (7). There seems to be no *a priori* reason for not having

$$\frac{1}{k'}=\frac{f(V)}{k}+g(V), \quad \ldots\ldots (15)$$

instead. Of course, if the transformation between k and k' is linear, that between $\frac{1}{k}$ and $\frac{1}{k'}$ is bilinear and conversely. In the latter case, an additional condition (for example, that $k=0$, implies $k'=0$)is necessary if (14) is to result. It follows that the choice made here (equation (7)) is to be preferred on the grounds of simplicity.

SUMMARY

A set of axioms is proposed for the derivation of Lorentz transformations in Bondi's " Radar Physics ".

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Lorentz Transformations and Invariance of Maxwell's Equations

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It is well known that one of the fundamental assertions of the Theory of Special Relativity is the invariance of Maxwell's equations under Lorentz transformations in a flat space time continuum. The converse of this result is that if Maxwell's equations are invariant under a certain general class of linear transformation then the latter belong necessarily to the representations of the Lorentz group. Validity of the converse is less frequently realized. We shall prove it in this note.

Let us write Maxwell's equations in the standard, four-dimensional notation :

$$f_{\mu\nu,\nu}=S_{\mu}, \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$f_{\mu\nu}=\varphi_{\nu,\mu}-\varphi_{\mu,\nu}, \quad \ldots\ldots\ldots \quad (2)$$

where Greek indices go from 1 to 4, comma denotes partial differentiation with respect to the coordinates x_{μ}, and the summation convention over repeated indices is used. φ_{μ} is the four-vector potential and S_{μ} the four-current density vector, and we restrict ourselves to a flat, pseudoeuclidean space time so that no distinction between covariant and contravariant vectors needs to be considered *a priori*. Indeed it is convenient to work in a linear vector space Σ to which x_{μ}, S_{μ}, etc., belong and in which the field tensor $f_{\mu\nu}$ represents an ordinary bilinear mapping.

The equations (1) and (2) are assumed to be invariant under a group of linear endomorphisms of Σ :

$$x'=Ax, \quad \ldots\ldots\ldots\ldots\ldots \quad (3)$$

which induce on any vector $v\varepsilon\Sigma$ an identical transformation

$$v'=Av. \quad \ldots\ldots\ldots\ldots\ldots \quad (4)$$

We shall say that the endomorphisms A form the Lorentz group if

$$AA^{T}=A^{T}A=I, \quad \ldots\ldots\ldots\ldots \quad (5)$$

the identity transformation, and A^{T} is the adjoint (or transpose) of A.

We assume that Σ admits an inner product, so that, for any $v\varepsilon\Sigma$, also $f\cdot v\varepsilon\Sigma$. The requirement of invariance implies that

$$(f\cdot v)'=f'\cdot v'. \quad \ldots\ldots\ldots\ldots\ldots \quad (6)$$

(6) is an additional assumption in the proof. However, it says little more than that f is a tensor field. It is sufficient to consider only the first set of Maxwell's equations (eq. (1)). The second set (eq. (2)) then serves to define the structure of the electromagnetic field. From equations (4) and (6), we have

$$f'\cdot v'=f'\cdot Av=(f'A)\cdot v=Af\cdot v,$$

so that

$$f'=AfA^{-1}. \quad \ldots\ldots\ldots\ldots \quad (7)$$

We can write equation (1) in the form

$$f\chi=s \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

where χ is the differential divergence operator. Then χ belongs to the dual space of Σ (e.g., Raikov, 1965) and therefore transforms according to the law

$$\chi=A^{T}\chi'. \quad \ldots\ldots\ldots\ldots\ldots \quad (9)$$

Since we have similarly to (6)

$$(f\chi)'=f'\chi', \quad \ldots\ldots\ldots\ldots\ldots \quad (10)$$

the last two equations give

$$f'\chi'=Af\chi'=AfA^{T}\chi,$$

or

$$f'=AfA^{T}. \quad \ldots\ldots\ldots\ldots\ldots \quad (11)$$

But the transformation (3) of the coordinates induces a unique transformation law of the field tensor. Hence, comparing (7) and (11), we have

$$A^{-1}=A^{T}, \quad \ldots\ldots\ldots\ldots \quad (12)$$

which is equivalent to the definition (5) of a Lorentz transformation.

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The First Commonwealth Statistician: Sir George Knibbs*

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The Constitution of the Commonwealth of Australia empowered the national government to engage in census-taking and statistical compilation and publication, and a *Census and Statistics Act* was passed in 1905, authorizing the creation of the Commonwealth Bureau of Census and Statistics. In the following year its work began under the direction of George Handley Knibbs.

(1) Biographical Notes

Knibbs was born in Sydney on 13th June, 1858, the son of John Handley Knibbs. He was educated as a surveyor and joined the General Survey Department of New South Wales in 1877, resigning in 1879 to take up private practice; in 1889–90 he joined the teaching staff of the University of Sydney's Engineering School as an independent lecturer in geodesy, astronomy and hydraulics, an appointment nominally held till 1905, when he was appointed Director-General of Technical Education for New South Wales and also Acting Professor of Physics at Sydney University. He joined the Royal Society of New South Wales in 1881 and was Honorary Secretary and Editor of its *Journal and Proceedings* for a total of nine years, and President in 1898–99. To 1906 he made 14 contributions to the Journal, mostly of a technical nature and arising from his work.[1]

He was also variously President of the Institution of Surveyors,[2] Sydney, of the New South Wales Branch of the British Astronomical Society,[3] and of the Society for Child Study. In 1902 he represented the University of Sydney on the board composing regulations for administering Cecil Rhodes' bequest providing scholarships to Oxford, and in 1902–03 travelled through Europe as a member of a commission on education.[4] He visited Europe from April to December, 1909, representing Australia at the International Congress on Life Insurance (Vienna), on the special committee revising the nomenclature of diseases (Paris), at an International Congress on the Scientific Testing of Materials (Copenhagen), at the International Institute of Statistics (Paris), and at the Geodetical Congress in London.

While Commonwealth Statistician, Knibbs sat on the board reporting on possibilities of the Canberra site and on the Royal Commission investigating the problems of trade and industry in war; he was a consulting member of the 1915 Committee on Munitions in War and sat on other wartime committees, and was chairman of the Royal Commission which in 1918–19 considered the taxation of Crown leaseholds. In 1919 he represented Australia at the London conference on double income tax and war profits, in 1920 attended the British Empire Statistician's Conference in London (chairing the Census Committee), and in 1921 was elected vice-president of the International Eugenics Congress, New York.

During his lifetime he received various honours, of which he was perhaps inordinately proud. He was created C.M.G. in 1911 and Knight Bachelor in 1923, was variously an Honorary Fellow of the Royal Statistical Society, a Fellow of the Royal Astronomical Society, an Honorary Member of the American Statistical Association and of the Statistical Societies of Paris and of Hungary, and a member of the International Institute of Statistics, the British Science Guild and the International Association for Testing Materials. In 1921 he presided over the Social and Statistical Section of the Conference of the Australasian Association for the Advancement of Science, and in 1923 was its General President.[5]

In 1921 Knibbs had left the Bureau to become Director of the newly constituted Commonwealth Institute of Science and Industry, resigning in 1926 and living in retirement till his death on 30th March, 1929.

* The bibliographical details for this note were drawn from the catalogue of the National Library of Australia and from the catalogue (incomplete) and shelves of the Library of the Commonwealth Bureau of Census and Statistics. Many references were traced through later citations.

(2) Knibbs as Statistician

Knibbs considered his duties to extend far beyond the boundaries of statistical collection and processing in fields dictated by others. He saw himself as " assisting the administrative statesman with his counsel and advice ",[6] and it was to this end that he published such works as his report on social insurance, where he elaborated an organic theory of the state and justified public health measures on the grounds of national development rather than humanitarianism.[7]

His major interest was in vital statistics, and it was here that he won his international reputation. Here too he became involved in theory, embracing at least in the later part of his life a doctrine he labelled " The New Malthusianism ". He considered that at current growth rates the world would reach human capacity in two and a half centuries. Although he advocated increased population for Australia as necessary for self-preservation, he warned against indiscriminate immigration, thus reflecting contemporary government policy as well as social thinking.[8]

Knibbs was a mathematician and statistician rather than an economist,[9] although he was concerned with studying such phenomena as unemployment and fluctuations in the purchasing power of money. His emphasis within statistics was on social problems and improvement of the human condition. In his data collection he was always hampered by lack of co-operation from his hoped-for respondents, for his expectations of others were high. His suggestions for a detailed nosological classification[10] would have placed considerable strain on the medical profession, despite its undoubted worth, and his cost of living enquiries[11] were too onerous for most housewives to respond. Knibbs was a keen advocate of international statistical co-operation, and in particular of an international statistical institute as an offshoot of the League of Nations, but he had to be satisfied with a less grandiose Imperial statistical bureau.[12]

(3) Knibbs and the Early Work of the Commonwealth Bureau of Census and Statistics

(i) *Unification of Statistical Collection*

Uniform statistical requirements for the Australian colonies were originally set by the British Government, but after the granting of responsible government divergences arose. In most States individual departments prepared their own statistics for a central collating department, and six pre-Federation conferences of State Statisticians failed to achieve uniformity in the methods, subjects and timing of statistical enquiries. Even in census-taking uniformity had proved impossible, although as the methods of individual colonies were based on United Kingdom practices they were similar. A conference of statisticians in Hobart in 1890, and another in Sydney in 1900, improved uniformity and effectiveness, but even so the presentation of the 1901 Census results was not uniform, and incomplete tabulation of results, and differences in the interpretation of terms meant Commonwealth totals were difficult to obtain in some cases.

The prime task of the newly established Bureau was therefore the achievement of uniformity, and a conference of State Statisticians and a New Zealand representative was held under Knibbs' presidency in 1906. The Commonwealth Statistician presented 150 forms ensuring comparability of State returns. Among the specific points he wished discussed were: the fixing of the areas to which various statistical aggregates should apply, as at that time territorial divisions for different purposes seemed unrelated and he felt it desirable to resolve the question before the 1911 census; the best method of estimating the quantity and value of production, and the means of obtaining statistics concerning primary and secondary production, all industries and finance; the attainment of greater precision in vital and social statistics and in estimates of the fluctuating populations of States; the accurate recording of interstate trade and the adoption of a uniform listing of items in Trade and Customs returns,[13] and the necessity for uniformity of the order of supply of information to the Commonwealth office and a suggested list of precedence.

It was resolved by the conference that the extent of compilation by State bureaux, and where the conference had adopted set forms, the method and date of compilation should be the same; that except for data collected in confidence the information in each bureau should be immediately available to other State bureaux and to the Commonwealth Statistician; that rapid population movement in Australia necessitated a quinquennial rather than decennial enumeration of population; that a monthly record of trade between States was necessary; that production statistics should not disclose data for individual concerns, or, more generally, that secrecy was necessary to retain public confidence; that the Commonwealth Statistician

should prepare instructions for uniform compilation and interpretation of data, and that he should decide all questions of mathematical method; and that publications of Commonwealth and States should be uniform in size and ordering of data.

(ii) *The Issue of the Official Year Book of the Commonwealth of Australia*

The issue of a *Year Book* was not new to Australia. Victoria's series began in 1873 when H. H. Hayter became Government Statist. New South Wales had its *Statistical Register* and Coghlan's annual *The Wealth and Progress of New South Wales* and *The Seven Colonies of Australasia.*

The first Commonwealth *Year Book*, published in 1908, contained statistics for the Federal period 1901–07, with corrected statistics for 1788–1900, such that the *Year Book* could become the authoritative source for Australian statistics. The statistics dealt with population and its characteristics, pastoral and agricultural production, forests, fisheries, and mines, manufacturing industries, domestic and foreign commerce, transport, communications, government and private finance, public instruction, justice, charity, local government, industrial matters and defence. The subject matter was to be viewed from three angles: the progress of Australia as a whole, its statistical comparisons with other countries, and the development of the States.

It was intended that each issue should contain not only statistics but articles dealing with special subjects of continuing interest such as the discovery, colonization and federation of Australia; its geography, geology, flora, fauna and climate; and land tenure and settlement. Most articles were to appear only once, though they might possibly be summarized in later issues. Use was to be made of maps, graphs and other diagrammatic representation.

The *Year Books* appear to have been well received by the public. Melbourne's *Argus* described the *Year Book* as "a monument to Knibbs' energy, clear-sightedness, and enthusiasm"[14] while *The Times* in a leading article, says of it: "The most wonderful book of its kind in the world . . . the creation of a genius . . . the Commonwealth Statistician, and there is no other publication in the Empire to compare with it".[15] As Knibbs' *Year Book* was but a development of Coghlan's compilation for New South Wales, such personal praise was perhaps a little misplaced.

(iii) *The First Commonwealth Census*

That Knibbs was personally interested in demographic and social statistics is evident from his later papers for the Royal Society of N.S.W.,[16] his works on nosology,[17] the Bureau's publications during his term,[18] and his works on the problem of world population.[19] He was concerned with the collection of comprehensive and useful data and with its mathematical analysis. His most important demographic collection was the first Commonwealth census, a major effort in organization.

The third part of the *Census and Statistics Act 1905* dealt specifically with the taking of the census, providing for a census in 1911 and in every tenth year thereafter. State supervisors were appointed, this being in all cases but one the State Statistician (Western Australia had the Chief State Electoral Officer). Each State was divided into census districts, in charge of enumerators who supervised individual collectors. The census date was selected as 3rd April, to coincide with the United Kingdom and other parts of the Empire, but this proved unsuited to local conditions as wet weather in Queensland delayed collection considerably.

Particulars to be specified in the schedule were laid down by the Act, mostly following existing State practices: name, sex, date of birth (or age last birthday only where actual date was unknown, for this resulted in a tendency for ages to be rounded to numbers ending in 0 or 5), condition as to, and date of existing marriage, relation to head of the household, sickness or infirmity (blindness or deaf-mutism), religion (optional query), education (whether able to read and write English or able to read only, illiterate, or receiving education), birthplace, length of residence in Australia if born abroad, and nationality. Profession or occupation was queried and the occupation of employer, or his industry, was investigated to help in classification. Eight main classes were distinguished in tabulation, including professional, domestic, commercial, transport and communication. These were eventually classified into 654 occupational groups. The grade of occupation was asked (e.g., employee). The occupation to be stated was that usually followed; if the respondent had been unemployed for more than one week the period was to be stated. The questions concerning period of unemployment and employer's industry were innovations. This information was to be furnished in respect of each person in each dwelling on the night in question. Also to be specified were the material of the outer walls of the dwelling and the

number of its rooms including kitchen and excluding bathroom. Under the Census Regulations the additional questions concerned—for persons—race, number of children (living or dead, from existing and/or previous marriage), date of arrival in Australia if born elsewhere (as a check on the length of residence query); for dwellings—the nature of the building (private home, hotel, etc.), whether the occupier was owner, tenant or rent purchaser, and the weekly rent payable or rental value per week.

Previously one schedule per dwelling had been used, with each personal query heading a vertical column and space for particulars of 20 persons provided horizontally. In this census each person was required to fill in, or to have filled in for him by the householder or the collector, a personal card. The householder was in addition required to fill in a card showing particulars of the dwelling and the numbers of personal cards enclosed, with names and sexes shown. The advantages of the personal cards were seen as numerous; firstly, they would ease the task of dealing with returns; secondly, the increased individual privacy allowed to persons such as residents of boarding houses was expected to call forth more accurate answers; the work of the householder would be lightened; and the risk of confusion on the householder's schedule was lessened. Collectors required to fill in locality details and check individual cards were less enthusiastic about their adoption, but Knibbs was always prepared to ask for more detailed information and time-consuming collection than respondents wished to give, as his own C.B.C.S. papers on vitality statistics show clearly. The householder's cards, besides giving information on dwellings and providing a check on personal cards, gave a summary of members of the household which could be used for a quick population count. Collectors kept compilation books in which they summarized population results, these summaries being checked by enumerators and passed quickly to the Commonwealth Statistician. State populations were required by the Commonwealth Electoral Office, and also by the Commonwealth Treasury for the allocation of *per capita* subsidies under the *Commonwealth Surplus Revenue Act*, 1910.

Although Knibbs on his visit overseas in 1909 had seen the organization and equipment of other bureaux and recent developments in scientific methods in census and statistics, he used neither tabulating nor sorting machines in the 1911 census as he felt the relatively small population and relatively simple combinations did not warrant them, but he introduced electrically-operated adding machines and some calculating machines. The card system, used in enumeration, was further employed in tabulation. Particulars of married couples were written on to conjugal cards before the household envelopes were destroyed and male and female cards separated. Answers were in some cases translated into a numeral code. The temporary tabulating staff was selected after an elementary examination by the Commonwealth Public Service Commissioner. Like collecting staff, they were bound by Declarations of Secrecy.

Results appeared in 17 *Census Bulletins*, with final results appearing in a full *Report*[20]; this included a review of census development from about 4000 B.C., of modern methods of census-taking and some modern censuses, and of the history of census-taking in Australia. The objects of the census were outlined as falling into four groups: demographic (population and its distribution in space, sex, age, conjugal condition, birth, marriage and death rates, and life tables); socio-economic (families, dwellings, education, religion, occupation, infirm/dependent, emolument, scope and continuity of employment); ethnographic (race, nationality and immigration); and statistical and administrative. The objects of the census, historical notes, organization of the census and instructions for complying with requirements were previously covered by Knibbs in a pamphlet[21] issued prior to census day and distributed for public guidance, in many cases to school children who were the most literate members of the families concerned. Also discussed in the *Report* were the various methods of enumeration, e.g., population *de jure* or *de facto* (the canvasser and householder methods, respectively) and the scope of the census, e.g., whether the request for a few particulars only resulted in a greater accuracy of the replies. A detailed account of the preliminary work of the census was given to help with the organization of future censuses.

Also included with the *Statistician's Report* (Vol. 1 of the census) is the post-censal adjustment of population estimates for the intercensal period 1901–11. The use of intercensal records of natural increase and net immigration resulted in an overstatement,[22] the main cause of the discrepancy apparently being unrecorded departures (e.g. late bookings on board ship). Also, the census recorded all persons on ships between Australian ports, whereas overseas migration figures referred only to passengers. The difficulties in intercensal estimates of State

populations and the need for at least a minor census quinquennially were discussed.

Detailed tables of census results for various classifications were given in Vols. II and III ; most gave separate results for males, females and total population. The combination of figures for males and females was considered inappropriate to life tables, and for the occupational classification the cost of publication of data by sex was not justified by the results offered. Volume I reported on the detailed tables and their significance.

Appendix A to the *Statistician's Report* was Knibbs' " Mathematical Theory of Population ". Knibbs said his purpose in preparing this monograph had been twofold : to create mathematical techniques of analysis of vital statistics, and to interpret material from the 1911 census. He suggested that the formulae developed might be of value to other investigations making use of statistical methods. He pointed out that although fluctuations in numbers and constituents of population, and its varying characteristics, might appear to be subject to complex and dissimilar forces that rendered them unsuited to mathematical analysis, in fact this type of analysis tended to make their trend more definite and reveal their significance. For this purpose changes had to be assumed to occur continuously by infinitesimal amounts. Concepts were developed and expressed in formulae for population in the aggregate, its age and sex distribution, masculinity, natality, nuptiality, fertility, mortality and migration.

(iv) *The Organization of the Labour and Industrial Branch of C.B.C.S.*

This branch was formed to investigate subjects such as trade unionism, wages and hours of labour, strikes and lockouts, the unemployed, prices, fluctuations in the exchange value of goods and the cost of living, apprenticeship and industrial education, the employment of women and children, production costs and the regulation and restriction of output. The first reports were published after much research into the techniques adopted by other countries.[23]

Knibbs began in 1912 the compilation of the first Australian indexes of retail, wholesale and overseas trade prices. Earlier overseas discussions had dealt with matters which were largely sterile from the point of view of historical interpretation, and concerned the use of different formulae to measure concepts which were only vaguely defined. This may account for the previous lack of interest in Australia, for the approach to abstract concepts from a mathematical point of view would have held little appeal for Coghlan, the able New South Wales Statistician, who might have been expected to have kept abreast with these developments. He was primarily interested in statistical data as an aid in interpreting economic tendencies, and certainly made a great deal of use of prices in analysis, but largely of prices of individual items designed to illustrate general tendencies. With a relatively narrow range of products available in the nineteenth century, the course of price changes could perhaps be more easily charted by reference to a few such commodities. These individual price series at least in the wholesale price area—or indexes of a few closely related commodities taken together—are back in fashion as analytical tools in preference to general wholesale price indexes.

Knibbs found an exhaustive examination of price movements had been necessitated by the influence of variations in the cost of commodities on the decisions of industrial tribunals and wages boards. The investigation demonstrated the need for rigorous techniques, and as a mathematician he was drawn to the intricacies of price index formulae. Much of his work on the theory of price index numbers turned out to have ephemeral interest only, but it did lead to the production of the first Australian price indexes on a clearly defined formula. His strong and articulate advocacy[24] of this, the fixed weights aggregative index formula, was a factor in its wide acceptance overseas for practical purposes. Not only were Knibbs' theoretical discussions of index number formulae of a high order, his empirical work was considerably more sophisticated than that of most of his overseas colleagues. Most practical data collection up to this stage, and particularly in the nineteenth century, had been with wholesale prices, but Knibbs' collection and measurement of purchasing power of retail prices—for food, clothing and house-rent, was in itself a progressive step. He was interested in differences in prices between places as well as between times. His first effort in overseas trade price indexes was a combined import and export price index which did not prove particularly useful and later in his term of office the publication of a separate export price index was begun, but no separate import price series appeared.

(v) *The War Census and Wealth Estimates*[25]

The war census was authorized by the *Commonwealth War Census Act* of 1915, and taken from 6th to 15th September, the onus of obtaining cards from post offices being on respondents.

Two schedules were issued, the first to be filled in by all males aged 18 and under 60, this being a personal card designed to obtain details of names, addresses, ages, marital status and dependants, occupations, health, military training, nationality and firearms held. To all respondents between 18 and 45 who were not enemy subjects were sent recruiting appeals. The second schedule was a wealth and income card, " to be filled in by all persons aged 18 or upwards possessed of property, or holding property on trust, or in receipt of income, and by other persons, companies, corporations, associations corporate or unincorporate, institutions, or other bodies specified in any proclamation under the War Census Act ". It asked names, addresses, motor vehicles possessed, a series of questions on income from various sources and a further series on real and personal property. War loan appeals and prospectuses were issued to those shown to possess £1,000 or more. Considerable tabulation of results was undertaken, by occupations of males and of females, average net income, the aggregate net assets of males and of females in each State, the average net assets per return, and classes of assets.

Knibbs used the war census records to prepare an incomplete estimate of the private wealth of Australia in 1915. His total was £1,643m. An inventory-method estimate gave £1,620m., which, when allowance was made for items such as locally held government securities included in the wealth census was increased to £1,760m. He suggested that a combination of wealth census and inventory methods would give the most satisfactory results, rejecting probate-return methods, as the outcome of his devolution estimates based on probate returns and an average rate of devolution (the outcome of an involved argument) was unsatisfactory. He also discussed the relationship between wealth and income, obtained a frequency relationship for both males and females, and graphed their wealth-income surfaces.

A quinquennial inventory estimate of wealth was suggested by Knibbs, supplemented by a decennial census of wealth. Inventory estimates were continued by Wickens, who provided parallel estimates of human capital.

(vi) *Other*

Apart from these four major projects with which Knibbs was certainly associated, the Bureau during his term produced a wealth of statistics covering demography and social statistics, transport and communication, finance, production, overseas trade, customs and excise.[26] Special reports were prepared on topical subjects such as social insurance and superannuation.[27]

(4) Conclusion

With ability and confidence evident in all his work, Knibbs won for the new office of Commonwealth Statistician considerable prestige, confounding those who had criticized his appointment. Certainly he had been a surprising choice in the light of his inexperience in the field, although it appears that the obvious candidate, T. A. Coghlan, who had proved an able State Statist for New South Wales for two decades, had declined a Federal offer in 1904.[28]

Knibbs' early training in pure rather than social science, like Coghlan's career as a civil engineer, fitted him mathematically for his new post ; but his preoccupation with mathematical excellence, while undoubtedly producing results of major significance, remained untempered by the degree of human interest and perception which endowed Coghlan's work with much of its character.

Was Knibbs' transfer from the post of Commonwealth Statistician a demotion, although naturally none of the Prime Minister's remarks in announcing the appointment hint at this ? It is possible that his failure to concern himself with current economic questions coupled with self-assurance and didacticism bordering on pomposity may have rendered him unpopular with both his colleagues and political masters. On the other hand, his personality may have belied his written expression of it, for one obituary[29] refers to his " charm of manner and his unvarying kindness of heart " and says that " unlike many whose lives are associated with advanced mathematics, he remained intensely human in his outlook on life ". Certainly his interests were extraordinarily wide—he even turned his talents to verse[30]—and his descriptive works are still well worth perusal for the detailed portraits they draw of his times.

Notes

[1] " A System of Accurate Measurement by Means of Long Steel Ribands ", *Journal and Proceedings of the Royal Society of New South Wales,* 1885, Vol. XIX ; " The Theory of Repetition of Angular Measures with Theodolites ", 1890, Vol. XXIV ; " The History, Theory and Determination of the Viscosity of Water by the Efflux Method ", 1895, Vol. XXIX ; " Note on Recent Determinations of the Viscosity of Water by the Efflux Method " and " The Rigorous Theory of the Determination of the Meridian Line by the Altaximuth Solar Observations ", 1896, Vol. XXX ; " The Theory of the Reflecting Extensometer of Professor Martens " and " On the Steady Flow of Water in Uniform Pipes

and Channels ", 1897, Vol. XXXI; the President's Anniversary Address appeared in 1899, Vol. XXXIII, with two further articles; " Observations on the Determination of Drought-intensity " and " Some Applications of and Developments of the Prismoidal Formula " in the same issue; " On the Relation, in Determining the Volumes of Solids, Whose Parallel Transverse Sections are n[ic] Functions of Their Position on the Axis, Between the Number, Position and Coefficients of the Sections and the (Positive) Indices of the Functions " and " The Sun's Motion in Space; Part I, History and Bibliography ", 1900, Vol. XXXIV; " The Theory of City Design ", " On the Principle of Continuity in the Generation of Geometrical Figures in Pure and Pseudo-homaloidal Space of n-Dimensions ", and " Some Theorems Concerning Geometrical Figures in Space of n-Dimensions Whose $(n-1)$ Dimensional Generatrices are n[ic] Functions of Their Position on an Axis, Straight, Curved or Tortuous ", 1901, Vol. XXXV; " The Hydraulic Aspect of the Artesian Problem ", 1903, Vol. XXXVI.

[2] Prize essay on *The Nature and Public Utility of Trigonometrical, General and Cadastral Survey*, published by the Institution of Surveyors, N.S.W., Inc., 1891.

[3] *The Place of Astronomy in a Liberal Education*, Presidential Address to the Annual Meeting of the British Astronomical Association, N.S.W. Branch, printed by S. E. Lees, Sydney, 1898.

[4] *Commission on Primary, Secondary, Technical and Other Branches of Education* (Commissioners Knibbs and Turner), Government Printer, Sydney, 1904–05.

[5] *Science and its Service to Man*, Presidential Address to the Australasian Association for the Advancement of Science at the New Zealand meeting, January, 1923. (Report of the Sixteenth Meeting, W. A. G. Skinner, New Zealand Government Printer.) This was a popular exposition of some scientific wonders, e.g. in astronomy and electronics.

[6] G. H. Knibbs, " The Problems of Statistics ", Report of the Twelfth Meeting of the Australasian Association for the Advancement of Science, held at Brisbane, 1909, p. 509.

[7] G. H. Knibbs, *Social Insurance*, J. Kemp, Government Printer, Melbourne, September, 1910. His " organic theory of the State " is outlined in Crawford Goodwin's *Economic Enquiry in Australia*.

[8] Shortly before his death he published *The Shadow of the World's Future* or *The Earth's Population Possibilities and the Consequences of the Present Rate of Increase of the Earth's Inhabitants*. Ernest Benn, London, 1928.

[9] Knibbs' successor, Charles Wickens, described him thus in an obituary. *Economic Record*, November, 1929.

[10] " The Classification of Disease and Causes of Death, from the Standpoint of the Statistician ", an address by Knibbs to the Victorian Branch of the British Medical Association which was subsequently printed in the *Intercolonial Medical Journal of Australasia* for 20th June, 1907 (reprint by Stillwell and Co.).

" Proposals of the International Statistical Institute regarding the Statistics of Tuberculosis ", reprinted from the *Transactions of the Eighth Session of the Australasian Medical Congress*. This was a translation of a paper presented by Dr. Jacques Bertillon to the 1907 Congress of the International Institute of Statistics. Also relevant here is " The Nomenclature of Diseases and Causes of Death ", a translation by Knibbs in 1907; a second edition, " Nomenclature of Diseases (Statistics of Morbidity-Statistics of Death) agreed upon by the International Commission charged with the Decennial Revision of the International Nosological Nomenclature (Bertillon Nomenclature) in its Second Session, 1909 ", including a Preface by Knibbs, was printed by W. A. Gullick, Government Printer, Sydney, 1910. " On the Statistical Opportunities of the Medical Profession " and " The Tuberculosis Duration Frequency Curves and the Number of Existing Cases Ultimately Fatal " were reprinted from the *Transactions of the Eighth Session of the Australasian Medical Congress* held at Melbourne in October, 1908. (J. Kemp, Government Printer, Melbourne.) " The International Nosological Classification and Accurate Certification of Causes of Death ", " The Secular Progress of Pulmonary Tuberculosis and Cancer in Australia for the past thirty years, their Annual fluctuation, and their frequency according to age ", " The Improvement in Infantile Mortality: its annual fluctuations and frequency according to age in Australia " and " The Secular and Annual Fluctuations of Deaths from Several Diseases in Australia; scarlet fever, measles, whooping-cough, diphtheria and croup, typhoid, diarrhoea and enteritis and dysentery, and the frequency of death according to age of this last " were reprinted from the Journal of the Australasian Medical Congress, Sydney, September, 1911. (W. A. Gullick, Government Printer, Sydney, 1913.)

[11] C.B.C.S. *Inquiry into the Cost of Living in Australia*, McCarron, Bird and Co., Melbourne, December, 1911, and in *Labour Report* No. 4, " Expenditure on Living in the Commonwealth, November 1913 ".

[12] G. H. Knibbs, " The Organisation of Imperial Statistics ", *Journal of the Royal Statistical Society*, 1920, pp. 201–14, and " Statistics in Regard to World and Empire Development ", Report of the Fifteenth Meeting of the Australasian Association for the Advancement of Science held in Melbourne, 1921, pp. 181–204.

[13] E.g., a suggested listing of categories of Trade and Customs. At the urgent request of the Department of Trade and Customs the 1906 figures were published alphabetically, but for 1907 the new list was adopted.

[14] *Argus*, 1st April, 1929.

[15] *Ibid.*, cited as " several years ago ".

[16] " On the Influence of Infantile Mortality on Birthrate ", and " Note on the Influence of Infantile Mortality on Birthrate ", in 1908, Vol. XLII; and *Abstract of Proceedings*, 1910, respectively. These were both reprinted as C.B.C.S. *Professional Papers*. " Studies in Statistical Representation: on the nature and computation of the curve $y-Ax^{m}e^{nxp}$ ", *Abstract of Proceedings*, 1910; " Statistical Applications of the Fourier Series, illustrated by the analysis of the rates of marriage, temperature, suicide, etc ", *Journal and Proceedings*, 1911; and (with F. W. Barford), " Curves, their Logarithmic Homologues, and anti-Logarithmic Generatrices; as applied to Statistical Data ", 1914, Vol. XLVIII. These three studies were reprinted as C.B.C.S. *Professional Papers*. " Suicide in Australia: a statistical analysis of the facts ", 1911, Vol. XLV. Reprinted as a C.B.C.S. *Professional Paper*. " Multiple Births, Their Characteristics and Laws Mathematically Considered ", 1925, Vol. LIX. " The Human Sex-ratio and the Reduction of Masculinity through Large Families ", 1925, Vol. LIX. " Note on the Occurrence of Triplets Among Multiple Births ", 1926, Vol. LX. " Protegenesis

and Ex-nuptial Natality in Australia ", 1927, Vol. LXI. " Rigorous Analysis of the Phenomena of Multiple Births ", 1927, Vol. LXI. " Proof of the Laws of Twin Births ", 1927, Vol. LXI.

[17] See footnote 10.

[18] The Bureau's *Population and Vital Statistics Bulletin* (which from 1921 became *Demography Bulletin*) commenced publication in 1907. Bulletin No. 1 was *Determination of the Population of Australia for each quarter from 31st December, 1900 to 31st December, 1906*, comprising a review of census methods, the methods of estimating population, and the results of each census of the several States of Australia; together with a complete tabular statement of the recorded fluctuations of the population of the several States since the inauguration of the Commonwealth. Bulletin No. 2 presented a *Summary of Commonwealth Demography for the years 1901–1906*, this being continued till 1910 on an annual basis; and annual bulletins (beginning with Bulletin No. 8 for 1907) of *Vital Statistics of the Commonwealth* similarly continued till 1910, after which the two were amalgamated in *Commonwealth Demography*, which appeared annually till 1918. Bulletin No. 3, *Vital Statistics of the Commonwealth for the quarter ended 31st March, 1907*, began a quarterly series which continued till 1911, after which it was incorporated in the *Monthly* (later *Quarterly*) *Summary of Australian Statistics*. A *Social Statistics Bulletin*—statistics as to Education, Hospitals and Charities, and Law and Crime—was published from 1907 to 1915.

[19] See footnote 8 also. " The Problems of Population, Food Supply and Migration ", in *Scientia*, Vol. XXVI (December, 1919).

[20] *Census of the Commonwealth of Australia taken for the night between 2nd and 3rd April, 1911. Vol. I* contained the *Statistician's Report*, including appendices. Appendix A was entitled *The Mathematical Theory of Population, of its Character and Fluctuations and of the Factors which influence them, being an Examination of the general scheme of Statistical Representation, with deductions of necessary formulae; the whole being applied to the data of the Australian Census of 1911, and to the elucidation of Australian population statistics generally*, and was also prepared by Knibbs. *Vol. II* contained parts 1–8 of the detailed tables (1. Ages, 2. Birthplaces, 3. Residence, 4. Education, 5. Schooling, 6. Religions, 7. Infirmities, 8. Aliens) and *Vol. III* parts 9–14 (9. Conjugal Condition, 10. Families, 11. Life Tables, 12. Occupations, 13. Dwellings, 14. Summary).

[21] *The First Commonwealth Census*, 3rd April, 1911: Notes (J. Kemp, Government Printer, Melbourne). " The Evolution and Significance of the Census " appeared in the *Addresses and Proceedings*, 1910, of the Imperial Federation League of Australia.

[22] The 31st March, 1901, census figures for Australian population were 1,977,928 M., 1,795,873 F., giving a total of 3,733,801; corresponding figures for 3rd April, 1911, were 2,313,035 M., 2,141,970 F., total 4,455,005. This total was adjusted back to 31st March, 1911; comparison with the intercensal estimates showed an overstatement of 70,265.

[23] *Report* No. 1 (1912) concerned " Prices, Price Index and Cost of Living in Australia ". The next *Report* dealing with this subject was No. 4, *Expenditure on Living in the Commonwealth, November 1913; Price Indexes, their Nature and Limitations etc.*; other *Reports* during Knibbs' term were No. 2, *Trade Unionism, Unemployment, Wages, Prices, and Cost of Living in Australia, 1891 to 1912*; No. 3, *Manufacturing Industries in the Commonwealth, 1912*; and Nos. 5–9, *Prices, Purchasing Power of Money, Wages, Trade Unions, Unemployment and General Industrial Conditions*. The quarterly Labour *Bulletin* appeared from March, 1913, till June, 1917, after which it was incorporated in the *Quarterly Summary of Australian Statistics*.

[24] *Labour Report* No. 1 had two appendices which bore Knibbs' name and contained most of the mathematical material: " Theory of Determining Price-indexes, Shewing Variations in the Exchange-value of Gold, or in the Cost of Living " (Appendix VIII) and " On the Establishment of a Basis for International Comparisons of the Exchange-value of Gold, and Variations in the Cost of Living " (Appendix IX). Appendix I gave a comprehensive bibliography of previous work on the subject. Knibbs' views were further developed in an article published by the American Statistical Association, " The Nature of an Unequivocal Price-index and Quantity-index ", which appeared in two parts in March and June, 1924. A less technical account appeared in " Price Indexes and Purchasing Power of Money ", a paper contributed to the Interstate Conference of Employers' Federations held in Melbourne in September, 1917, and issued by the Central Council of Employers in Australia, Melbourne, McCarron, Bird and Co., while his final word in the *Labour Reports* appeared in No. 9 (1918), *Price-indexes, Their Nature and Limitations, the Technique of Computing Them, and Their Application in Ascertaining Power of Money*, which had previously been published separately.

[25] The War Census of 1915 was reported in *The Private Wealth of Australia and its Growth as ascertained by various methods, together with a Report of the War Census of 1915*, published in 1918, McCarron, Bird and Co., Melbourne. Knibbs also contributed " The Private Wealth of Australia and its Growth " to M. Atkinson (ed.) *Australia: Economic and Political Studies, 1920*.

[26] In addition to publications mentioned in earlier footnotes, an annual *Transport and Communication Bulletin* was issued, the first covering the period 1901 to 1906, the second 1901 to 1908, the third 1901 to 1909, and so on. An annual *Finance Bulletin* also appeared, the first covering 1901 to 1907, 1916–17 to 1918–19 appeared in one volume, and future issues were to be biennial. The *Production Bulletin* was also annual, covering 1901–06, 1901–08, 1907–09, and so on.

The Commonwealth's Trade and Customs Returns were at first prepared by the New South Wales Government Statistician for the Minister for Customs; in 1907 the Bureau of Census and Statistics published *Trade and Customs and Excise Revenue of the Commonwealth of Australia for the year 1906*. It continued to appear annually—with a change of financial year basis from 1914–15—and eventually became the *Oversea Trade Bulletin*. *Shipping and Overseas Migration of the Commonwealth of Australia* was issued by the Bureau for the period 1906 to 1915–16, when it was discontinued. It replaced the Department of Trade and Customs *Annual Statement of Navigation and Shipping*. A monthly bulletin of trade, shipping and overseas migration statistics appeared from January, 1907; from January, 1912, this became the *Monthly Summary of Australian Statistics*; after September, 1917, this became the *Quarterly Summary of Australian Statistics* which has already been mentioned above as incorporating other published statistics.

The Bureau's major publication of a comprehensive nature has always been the *Official Year Book*, but a smaller publication, with description and statistics, was *The Australian Commonwealth : its resources and production*, which appeared annually from 1908 to 1915. *A Pocket Compendium of Commonwealth Official Statistics* was issued in 1913, 1914, 1916, and annually from 1918. (In 1916, it was published as a *Commonwealth Statistical Digest*.)

In addition, Knibbs edited " Miscellaneous Notes on Australia, its People and their Activities " in the Federal Handbook prepared in connection with the eighty-fourth meeting of the British Association for the Advancement of Science, held in Australia in August, 1914.

[27] Four special reports were prepared by Knibbs under Ministerial direction : *The Desirability of Improved Statistics of Government Railways in Australia* (February, 1909) ; *Social Insurance* (September, 1910, J. Kemp, Government Printer, Melbourne) ; *Superannuation* (October, 1910, J. Kemp, Government Printer, Melbourne) ; and *Local Government in Australia* (July, 1919, A. J. Mullet, Government Printer, Melbourne). He also compiled *Australian Life Tables, 1901–1910* (McCarron, Bird and Co., Melbourne, 1914), tables based on mortality experience of the Commonwealth of Australia, 1901–1910. *Australian Joint Life Tables, 1901–1910* were published in 1917.

[28] See E. C. Fry's 1965 A.N.Z.A.A.S. address, *T. A. Coghlan as an Historian*, and Joan M. Cordell, " T. A. Coghlan, Government Statist of New South Wales, 1886–1905 ", thesis submitted to the Department of Statistics, University of Sydney, 1960.

[29] *Melbourne Argus*, 1st April, 1929.

[30] *Voices of the North : and Echoes of Hellas*, Alston Rivers Ltd., London, 1913. Scandinavian and Greek sagas respectively.

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Triassic Stratigraphy—Blue Mountains, New South Wales

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Abstract—Geological mapping in the Blue Mountains revealed previously unknown Narrabeen Group sediments in Glenbrook Creek and a modification of the previously recognized western boundary of the Hawkesbury Sandstone. Examination of the Hawkesbury Sandstone-Narrabeen Group stratigraphic boundary indicates that the Burralow Formation (upper Narrabeen) thins and undergoes a facies change in a westward direction. At the westernmost extent of the Hawkesbury Sandstone, between Hazelbrook and Lawson on the Great Western Highway, the Burralow Formation, although probably still present, cannot be distinguished from the Grose Sandstone.

Within the massive Grose Sandstone there are two extensive continuous reddish-brown claystone horizons which are used for subdivision and marker horizons.

Introduction

The Triassic Narrabeen Group exposed in the Blue Mountains of New South Wales (Figure 1) is a sequence of more than 1,000 feet of quartz lithic to quartzose sandstone, claystone and shale. The Narrabeen Group lies with apparent conformity on top of coal-bearing sediments of Permian age and is in turn overlain by the Triassic Hawkesbury Sandstone. There is no evidence of a major break in sedimentation throughout the sequence.

The purpose of this study was to examine the stratigraphy of the Narrabeen Group and to determine criteria for establishing the position of the Narrabeen Group-Hawkesbury Sandstone boundary.

Stratigraphy

Although the sandstones of the Blue Mountains appear to be flat-lying in individual outcrops, they possess a regional dip to the east. A slight change in dip accompanies the change from the Hawkesbury Sandstone to the Narrabeen Group. East of the Woodford Main Ridge the dip is $1\frac{1}{2}°$, while west of the ridge it is slightly steeper at between $2°$ and $2\frac{1}{2}°$. The Woodford Main Ridge represents the most westerly ridge made up completely of Hawkesbury Sandstone.

The Triassic Narrabeen Group in the Blue Mountains of New South Wales has been subdivided into three formations by Crook (1956). Within these formations Goldbery (1966) recognized various members. The stratigraphic position and subdivisions of the formations are shown in Table 1.†

Caley Formation

The Caley Formation (Crook, 1956) is the basal unit of the Narrabeen Group in the Blue Mountains. It immediately overlies with apparent conformity the uppermost coal seam of the Illawarra Coal Measures, the Katoomba Seam, while the top of the unit is determined by the presence of the prominent, massive sandstones of the overlying Grose Sandstone.

Crook (1956) measured a provisional partial section of the Caley Formation, one mile east of Mount Caley in the Grose River Valley. Goldbery (1966) subdivided the Caley Formation into five members, and at Beauchamp Falls, near Blackheath, measured a full section which he proposed as the type section for the formation.

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† A complete geological map too large for publication may be examined at the School of Applied Geology, University of New South Wales (Goodwin, 1968).

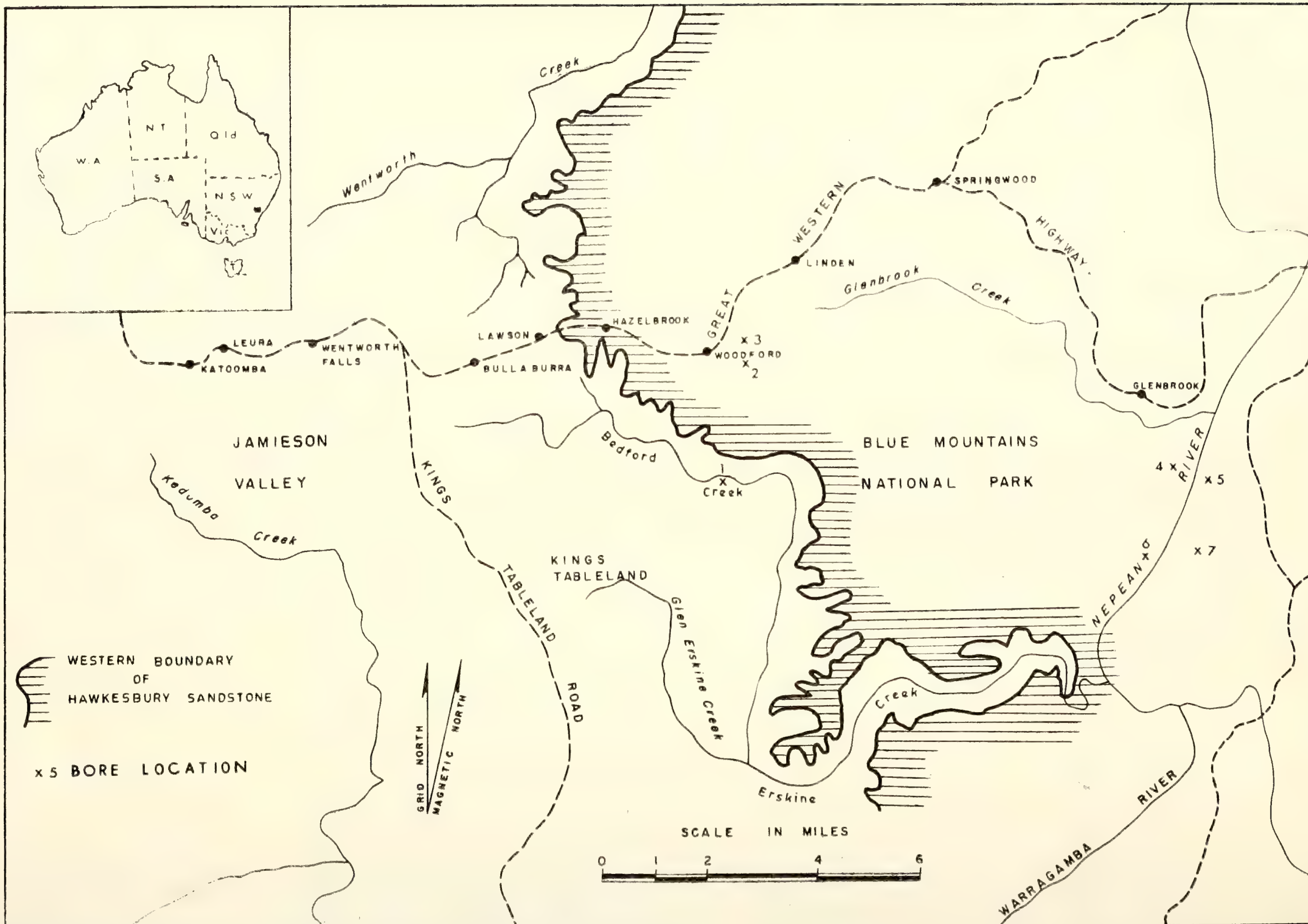

FIG. 1.—The study area showing the Hawkesbury-Sandstone–Narrabeen Group boundary and borehole localities: (1) Bedford Creek, (2) Woodford No. 1, (3) Woodford No. 2, (4) Euroke, (5) Mulgoa, (6) Breakfast Creek, (7) A.O.G. Mulgoa No. 2.

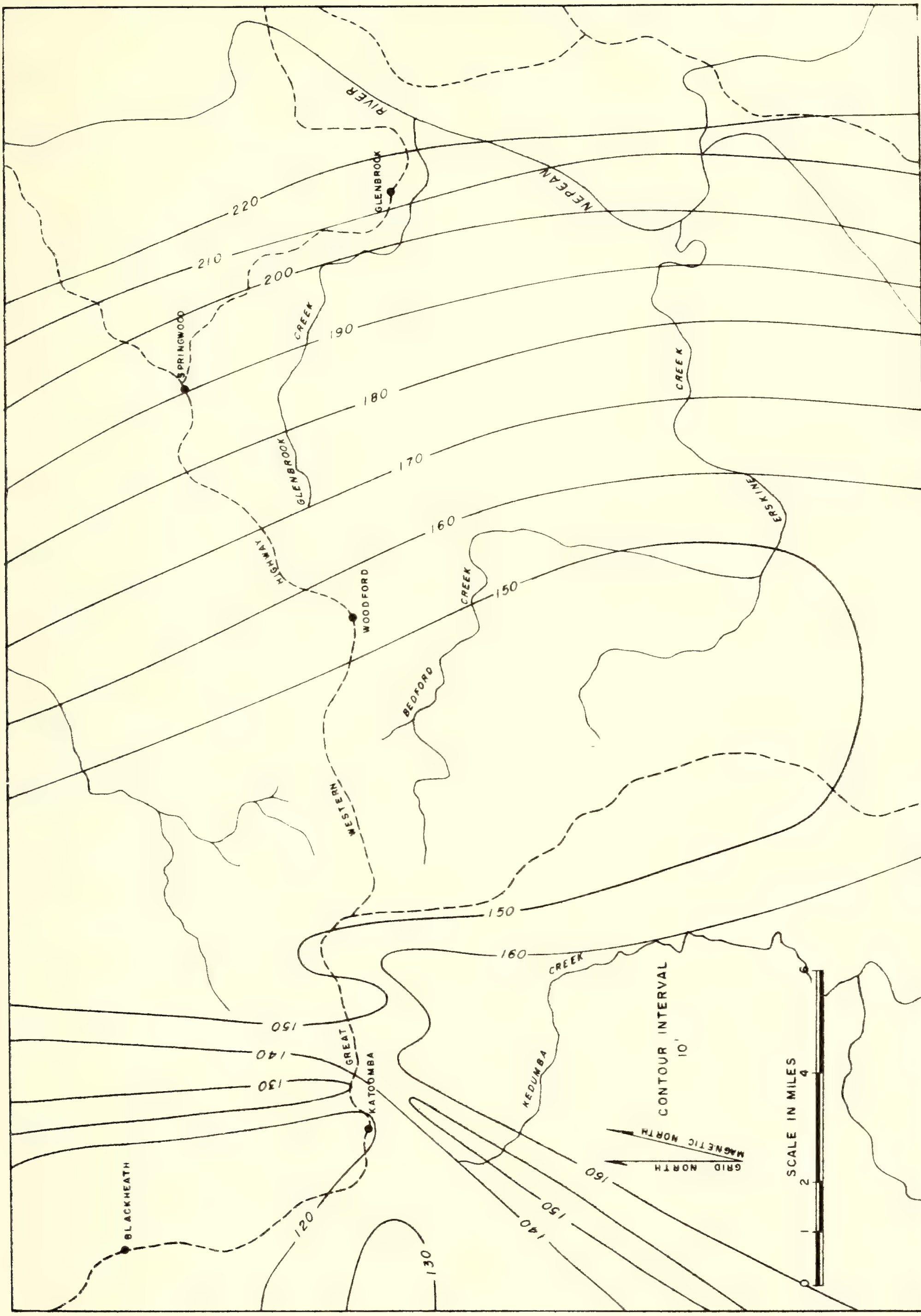

FIG. 2.—Isopach map of the Caley Formation.

TABLE 1
Stratigraphy of the Blue Mountains

System	Group	Formation	Member
TRIASSIC	Wianamatta Group	Ashfield Shale Mittagong Formation	
	Hawkesbury Sandstone		
	Narrabeen Group	Burralow Formation	
		Grose Sandstone	Banks Wall Sandstone
			Mount York Claystone
			Burra-Moko Head Sandstone
		Caley Formation	Hartley Vale Claystone
			Govett's Leap Sandstone
			Victoria Pass Claystone
			Clwydd Sandstone
			Beauchamp Falls Shale
PERMIAN	Illawarra Coal Measures		

The Caley Formation crops out at the base of the cliffs from Narrow Neck Peninsula to McMahon's Point, and in parts of Erskine Creek. The formation thickens to the east and south (Figure 2). At Katoomba it is 120 feet thick, whereas in the Bedford Creek Bore (Figure 1) it measures 162 feet. In the Kurrajong Heights No. 1 Bore located to the north and east of the study area the unit has a thickness of 250 feet.

In the Blue Mountains the Caley Formation has been subdivided into the five members of Goldbery (1966). However, in the Erskine Creek area, the middle member, the Victoria Pass Claystone is absent. The Caley Formation is distinguished from the Grose Sandstone by the presence of greater quantities of shale and claystone and by a slightly higher lithic content of the sandstones.

Within the Caley Formation the thickness of individual members is quite variable, however the overall thickness of the formation changes only gradually. The lithology of the Caley Formation is discussed with reference to the individual members.

Beauchamp Falls Shale Member

In all sections examined the Beauchamp Falls Shale forms the basal member of the Caley Formation. It is overlain by the Clwydd Sandstone and underlain by the Katoomba Seam, the uppermost unit of the Illawarra Coal Measures. It consists of interbedded carbonaceous shales, siltstones, claystones and fine-grained sandstones, a lithology which is distinctive in outcrop and easily identifiable even where the Katoomba Seam is absent.

A fluctuating depositional environment has produced marked variations in the thickness of this unit. In the Bedford Creek Bore it measures 31 feet 4 inches, at Wentworth Falls 17 feet, at the Valley of the Waters 28 feet, at Leura Falls 5 feet 8 inches, and at the Giant Stairway, Katoomba, 12 feet 9 inches.

Clwydd Sandstone Member

The predominant lithology of the Clwydd Sandstone is a coarse-grained quartz lithic sandstone. Occasionally this member contains fine-grained sandstones and lenticular claystones. Red and green subangular jasper pebbles up to $\frac{1}{4}$ inch in diameter are not uncommon in the coarse fraction.

The thickness of the member is variable. At Golden Stairway on Narrow Neck Peninsula, it is 17 feet, in the Bedford Creek Bore 26 feet 4 inches, while in Erskine Creek, where the

Victoria Pass Claystone is absent, it attains a maximum thickness of 130 feet.

Victoria Pass Claystone Member

The Victoria Pass Claystone is the middle unit of the Caley Formation. It is recognizable by the hard dense grey claystone of which it is made up and the tendency of the unit to be eroded, forming a notch in the cliff face. The absence of the Victoria Pass Claystone in Erskine Creek makes the distinction between the Clwydd Sandstone and the Govett's Leap Sandstone tenuous.

The thickness of the Victoria Pass Claystone is variable. In the Bedford Creek Bore it is 17 feet 1 inch thick and is comprised of fine grey shale with some silty bands. Along the cliffs from Wentworth Falls to Katoomba, a distance of four miles, variations in thickness are quite apparent. At Wentworth Falls the thickness is 7 feet 1 inch, at Valley of the Waters 24 feet, at Leura Falls 9 feet, and at the Giant Stairway, Katoomba, 4 feet 6 inches.

With the exception of the Bedford Creek Bore, there is little variation in lithology throughout the study area. It is composed of a medium to dark grey, hard, dense claystone.

Govett's Leap Sandstone Member

The Govett's Leap Sandstone is a fine- to coarse-grained quartz lithic sandstone. It contains a clay-rich matrix that tends to render the rock quite friable. In the Bedford Creek Bore the basal 4 feet 7 inches of the Govett's Leap Sandstone is a fine, light greenish grey conglomerate. This is the only occurrence of conglomerate in the Caley Formation within the study area.

The thickness of the Govett's Leap Sandstone is variable. In the Bedford Creek Bore it is 57 feet 8½ inches, while at Leura Falls it is 83 feet, and at the Golden Stairs on Narrow Neck Peninsula only 33 feet 6 inches.

Hartley Vale Claystone Member

The Hartley Vale Claystone is the uppermost unit of the Caley Formation. It is distinctive as a fine-grained unit that usually forms a notch on the cliff face due to erosion and marks the base of the cliff, forming Grose Sandstone. The less resistant nature of this unit and the tendency of the overlying Grose Sandstone to fracture along vertical joint planes is presumably the reason for the formation of the great precipices for which the Blue Mountains are famous. If the Hartley Vale Claystone were more resistant to erosion than the Grose Sandstone, the development of talus slopes, similar to those associated with the Burralow Formation, would be expected.

The lithology of the Hartley Vale Claystone ranges from fine-grained sandstone to claystone and shale. The average thickness of the unit is 8 feet and variations are relatively small. With the exception of the Valley of the Waters, the unit is easily recognizable throughout the area studied. At the Valley of the Waters the lower portion of the Grose Sandstone contains numerous claystone bands and the precise position of the boundary between this unit and the underlying Caley Formation is uncertain.

Grose Sandstone

The Grose Sandstone, the middle formation of the Narrabeen Group, was named by Crook (1956) after the outcrops in the Grose River Valley. Here the massive sandstone attains thicknesses of 700 feet and forms majestic cliffs. The Grose Sandstone also forms the cliffs of the Jamieson and Megalong Valleys.

The Grose Sandstone crops out on the surface of the Blue Mountains Plateau from Lawson to Katoomba and in many of the river valleys in the study area. It has been subdivided into three members by Goldbery (1966).

Grose Sandstone :

- Banks Wall Sandstone Member.
- Mount York Claystone Member.
- Burra-Moko Head Sandstone Member.

The presence of the Mount York Claystone Member was confirmed by the author, who also found another continuous claystone horizon, usually distinctive by its reddish brown coloration, below the Mount York Claystone. This lower claystone is very useful as a marker horizon and can be used for mapping purposes. In order to prevent the nomenclature from becoming chaotic, this lower red brown claystone has not been given member status but herein is referred to as the " Unnamed Claystone Marker Bed ".

Unnamed Claystone Marker Bed*

The " Unnamed Claystone Marker Bed " is a lower reddish brown claystone which crops out an average of 150 feet above the base of the Grose Sandstone. Generally it occurs between 130 and 170 feet above the base of the Grose

* At the time of writing the nomenclature of the Blue Mountains is in a state of revision (see " Geology of the Western Blue Mountains ", N.S.W. Geol. Survey Bull. 20). Until finalized, the informal name of Katoomba Claystone is proposed for this unit.

Sandstone, whereas the Mount York Claystone is located 340–400 feet above that level. Along the cliff faces these two horizons are easily recognized by (1) their red coloration, (2) their weathering to form an erosional notch, and (3) by a line of trees commonly growing upon them. The reddish brown coloration is in places intermittent, although persistent, and represents the only reddish-brown claystones in the Narrabeen Group of the study area.

The " Unnamed Claystone Marker Bed " is continuous and may be traced along the cliffs from Narrow Neck Peninsula (Plate I) to McMahon's Point, a distance of almost 20 miles. It is evident in the Bedford Creek Bore, where the base is 127 feet above that of the Grose Sandstone and the thickness is 8 feet 6 inches. The contacts with the sandstones above and below are sharp and straight, virtually no brecciation or gradation being observed. In some stratigraphic sections, such as at the Giant Stairway, Katoomba, the claystone is split into several bands. The claystone bed normally forms an erosional notch on the cliff face (Plate II), while the colour varies from reddish brown to mottled, white and light grey.

The existence of this horizon was not noted by Goldbery (1966) in the Grose Valley. He does refer to a reddish-brown claystone, 5 feet 6 inches thick, in his Govett's Leap Stratigraphic Section, but states that it is lenticular " when observed on the nearby cliff face ".

The continuity and relatively constant thickness make the " Unnamed Claystone Marker Bed " useful for correlation and mapping. It is felt that re-examination of adjacent areas such as the Grose Valley and Burragorang Valley will show the presence of this horizon.

Burra–Moko Head Sandstone Member

The lower member of the Grose Sandstone, the Burra-Moko Head Sandstone, has a maximum thickness in the study area of 670 feet at the Bedford Creek Bore. The unit thickens in a north-easterly direction (Figure 3) across the mapped area. The anomalous thickness centred on the Bedford Creek Bore location is a localized depositional high. The Mount York Claystone does not occur in the bore. A reddish brown claystone outcrops 80 feet above the level of the top of the bore and can be traced upstream several miles, where it can be correlated with the Mount York Claystone in several stratigraphic sections measured as a part of this study.

The lithology is medium- to coarse-grained quartz lithic sandstone. Quartzose sandstone is rare in this member. Lenticular claystones and shales are common and range up to 3 feet in thickness. The sandstones are often cross-stratified. The bedding is usually massive and the matrix is rich in clay minerals which tend to render the sandstone friable. Quartz pebbles up to 1 inch are common. Ironstone concretions are prevalent, however they are not as abundant as in the Banks Wall Sandstone Member.

Goldbery (1966) postulated a rapid thinning of this member in the Katoomba-Blackheath area ; however, this characteristic has not been substantiated by the present study. It would appear that Goldbery correlated the " Unnamed Claystone Marker Bed " at Kanimbla Valley, Megalong Valley, Narrow Neck Peninsula, Scenic Hill and Victoria Pass, with the Mount York Claystone along the western edge of the area covered by his study.

Mount York Claystone Member

The Mount York Claystone is a reddish brown claystone which occurs as a single bed or two closely spaced beds with a thin sandstone bed separating them. It occurs between 340 and 400 feet above the base of the Grose Sandstone and crops out continuously in the western Blue Mountains.

The claystone ranges from reddish brown, mottled or white to light grey, although it is unusual for the claystone to persist more than 100 yards without some red coloration being present. Along the Kedumba Walls the Mount York Claystone outcrops close to the top of the cliffs and occasionally, because of irregularities in the height of the cliffs, outcrops on the surface of the plateau.

Banks Wall Sandstone Member

The Banks Wall Sandstone is the uppermost member of the Grose Sandstone in the Blue Mountains. Because of the absence of the Burralow Formation west of Hazelbrook, it is not possible to assign a definite thickness to this unit although it is in the order of 350 feet. At Euroka Trig, which was the only place where a full section was measurable, the thickness is 325 feet ; however, it is not known if this value is typical. Goldbery (1966) reports a maximum thickness of 370 feet in the Upper Grose Valley.

The Banks Wall Sandstone crops out along the surface of the plateau from Lawson to Katoomba and comprises the surface outcrop of the plateau as far south as Lake Burragorang. It also crops out further east in the major river valleys, the most notable being Erskine Creek.

Unnamed claystone marker bed on Narrow Neck Peninsula.

Unnamed claystone marker bed, Wentworth Falls. Note erosional notch.

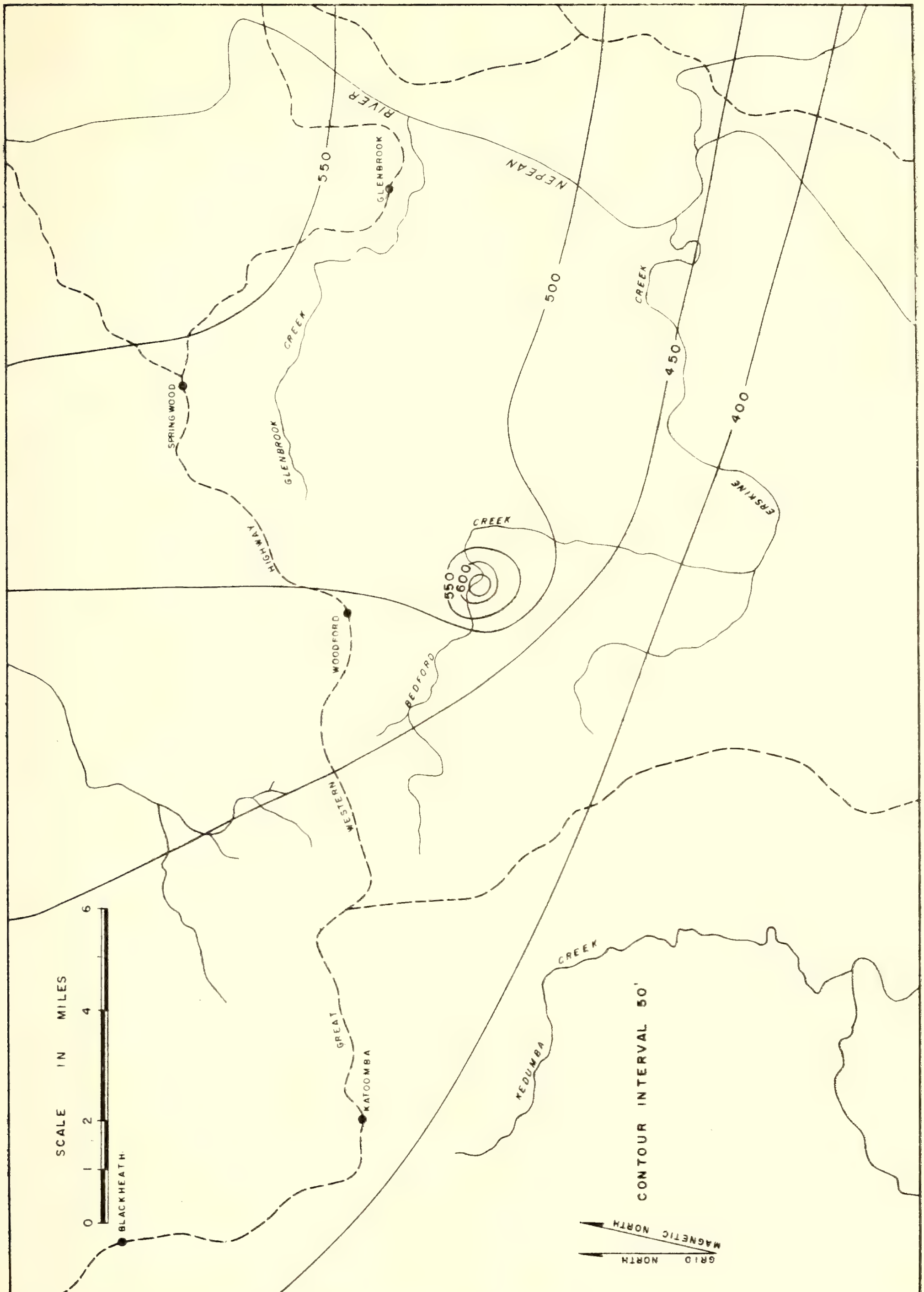

Fig. 3.—Isopach map of Burra-Moko Head sandstone.

The sand is quartzose with a small percentage of lithic fragments. The percentage of lithic material in the sandstone increases towards the base. Cross-stratification is common, as are ironstone bands, which are usually oriented sub-parallel or at random to the bedding planes. Lenticular claystones occur throughout the sandstone and increase in abundance toward the base.

Burralow Formation

The Burralow Formation is the uppermost unit of the Narrabeen Group. The Burralow Formation is overlain by the Hawkesbury Sandstone and underlain by the Grose Sandstone.

The lithology of the Burralow Formation consists of fine-grained micaceous sandstones, claystones and shales. Full sections of the formation are rare and outcrops are generally poor due to the occurrence of talus slopes. The formation has a high percentage of sandstone ; however, due to the nature of outcrop, it was not possible to distinguish the Tabarag Sandstone Member described by Crook (1956).

The extent of outcrop (Figure 4) closely approximates that of the overlying Hawkesbury Sandstone (Figure 6) and the variations in thickness are proportionate. In the Mulgoa No. 2 bore on the eastern edge of the study area the thickness is 400 feet, while in the Kurrajong Heights No. 1 bore to the north and east of the study area a thickness of 540 feet was recorded.

From the eastern boundary of the Blue Mountains, the Lapstone Monocline, the Burralow Formation increases in grain size and sand content in a westward direction. At the western edge of outcrop near Hazelbrook, the Burralow Formation is indistinguishable from the Grose Sandstone. This change in facies (Figure 5) makes recognition of the Burralow Formation difficult towards the western edge of outcrop and where definite recognition was impossible the strata have been mapped as Grose Sandstone.

The micaceous character of the sandstones is persistent throughout the entire area of outcrop. On the eastern part of the study area the formation is composed of numerous claystone shale and siltstone bands, alternating with fine- to medium-grained micaceous quartz-rich sandstones with only a few lithic fragments. Toward the west the argillaceous bands become less frequent and the sand becomes medium- to coarse-grained and sub-lithic in character. Cross stratification is rare in the Burralow Formation and reddish-brown claystones are completely absent.

Narrabeen Group-Hawkesbury Sandstone Boundary

A number of criteria for the recognition of a Narrabeen Group-Hawkesbury Sandstone boundary have been proposed by Standard (1961, 1964), Galloway (1965, 1967) and Goldbery (1966). The main field criteria used during this study to distinguish the Hawkesbury Sandstone from the Narrabeen Group (Figure 1) were :

(1) The lithological change in character of the sandstones from a quartzose nature in the Hawkesbury Sandstone to a sub-lithic and then to a quartz-lithic nature within the Narrabeen Group.

(2) The occurrence of a coarse quartz conglomerate at the base of the Hawkesbury Sandstone. In the eastern portion of the study area the occurrence of this conglomerate horizon is quite consistent.

The pebbles, ranging up to 2 inches in diameter, consist of quartz and are cemented by silica. The thickness of the conglomerate is variable, the maximum thickness recorded being 10 feet 6 inches at Linden Tank.

(3) The increasing frequency and size of the quartz pebbles in the Hawkesbury Sandstone as the conglomerate horizon and the base of the Hawkesbury Sandstone is approached. This observation may be useful for the examination of a large stratigraphic interval as no true marker beds exist within the Hawkesbury Sandstone.

(4) The fine-grained micaceous nature of the sandstones and the regularity of the interbedded shales and claystones of the top of the Burralow Formation over the eastern portion of the study area. The lateral lithofacies change in a westward direction to a medium-grained sand makes the differentiation between the Burralow Formation and the Hawkesbury Sandstone difficult. On the western margin of outcrop of the Hawkesbury Sandstone the only possible distinction is the slightly more lithic character of the Narrabeen Sandstones.

(5) The increase in clay content, as matrix, of the Narrabeen sandstones. This change is relatively abrupt and distinctive in the eastern portion of the area ; however, approaching the westward limit of outcrop of the Hawkesbury Sandstone the clay content of the Hawkesbury Sandstone increases and this characteristic is no longer useful for distinction.

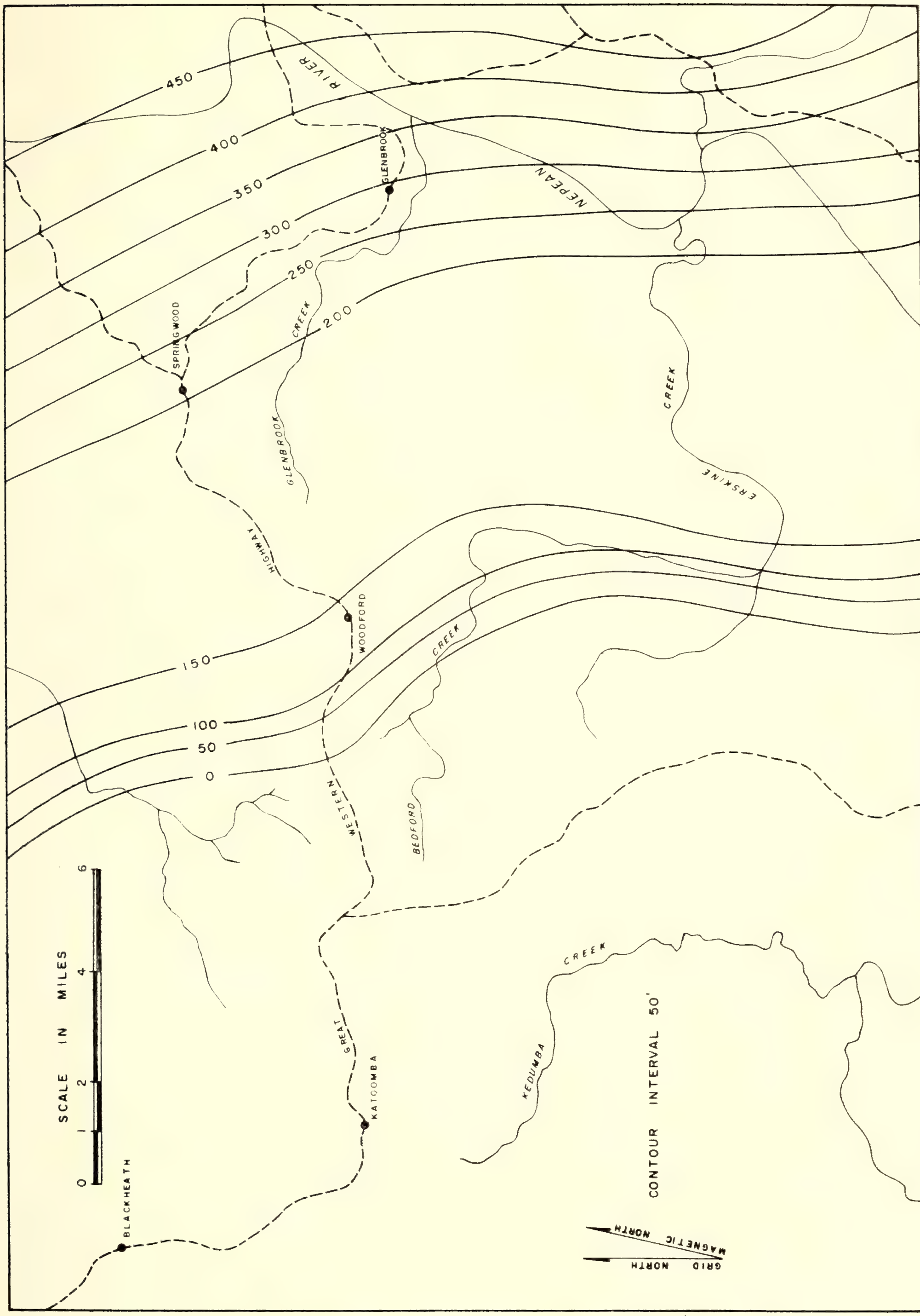

Fig. 4.—Isopach map of Burralow Formation.

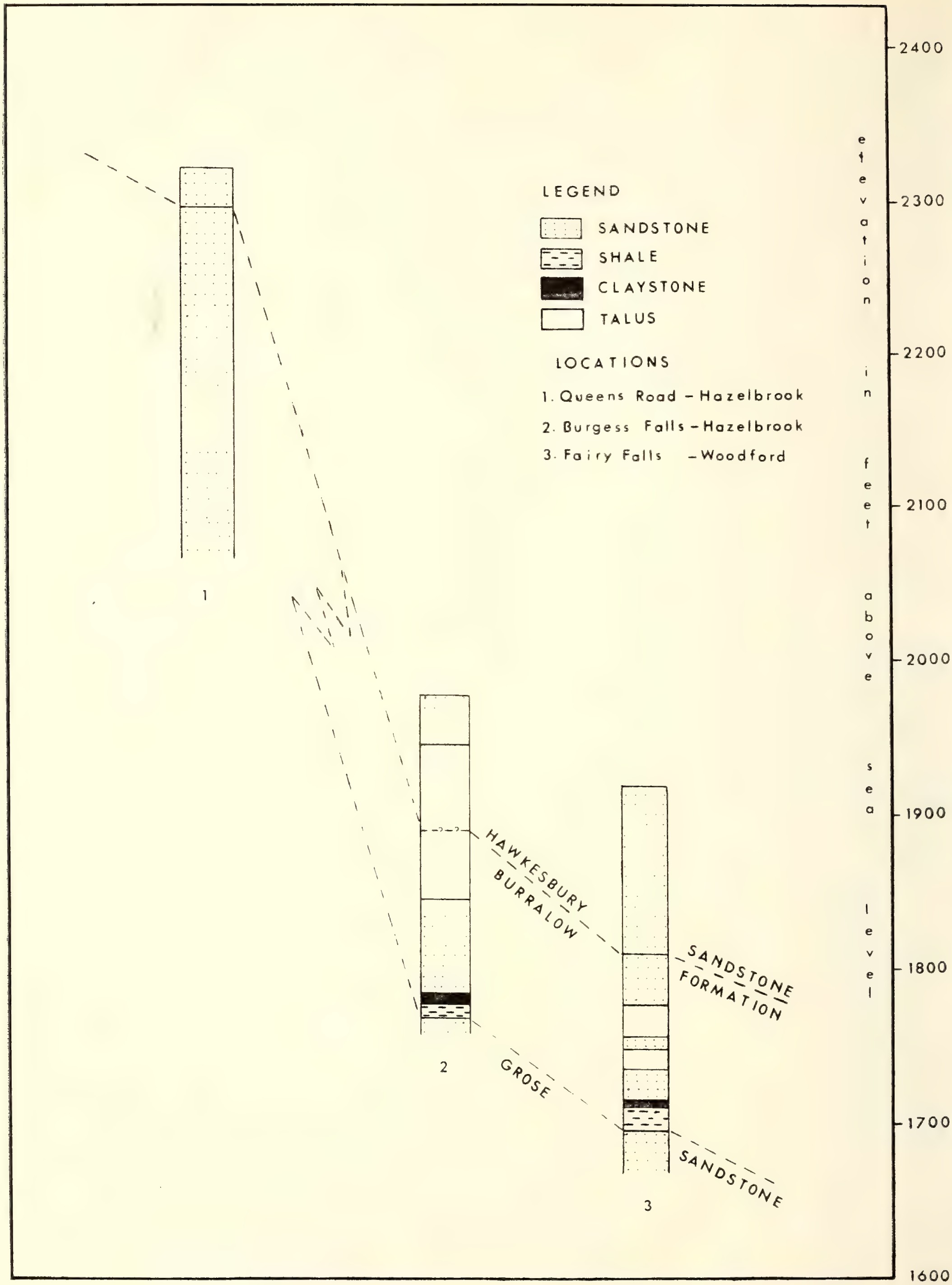

Fig. 5.—Stratigraphic cross-section Woodford to Hazelbrook.

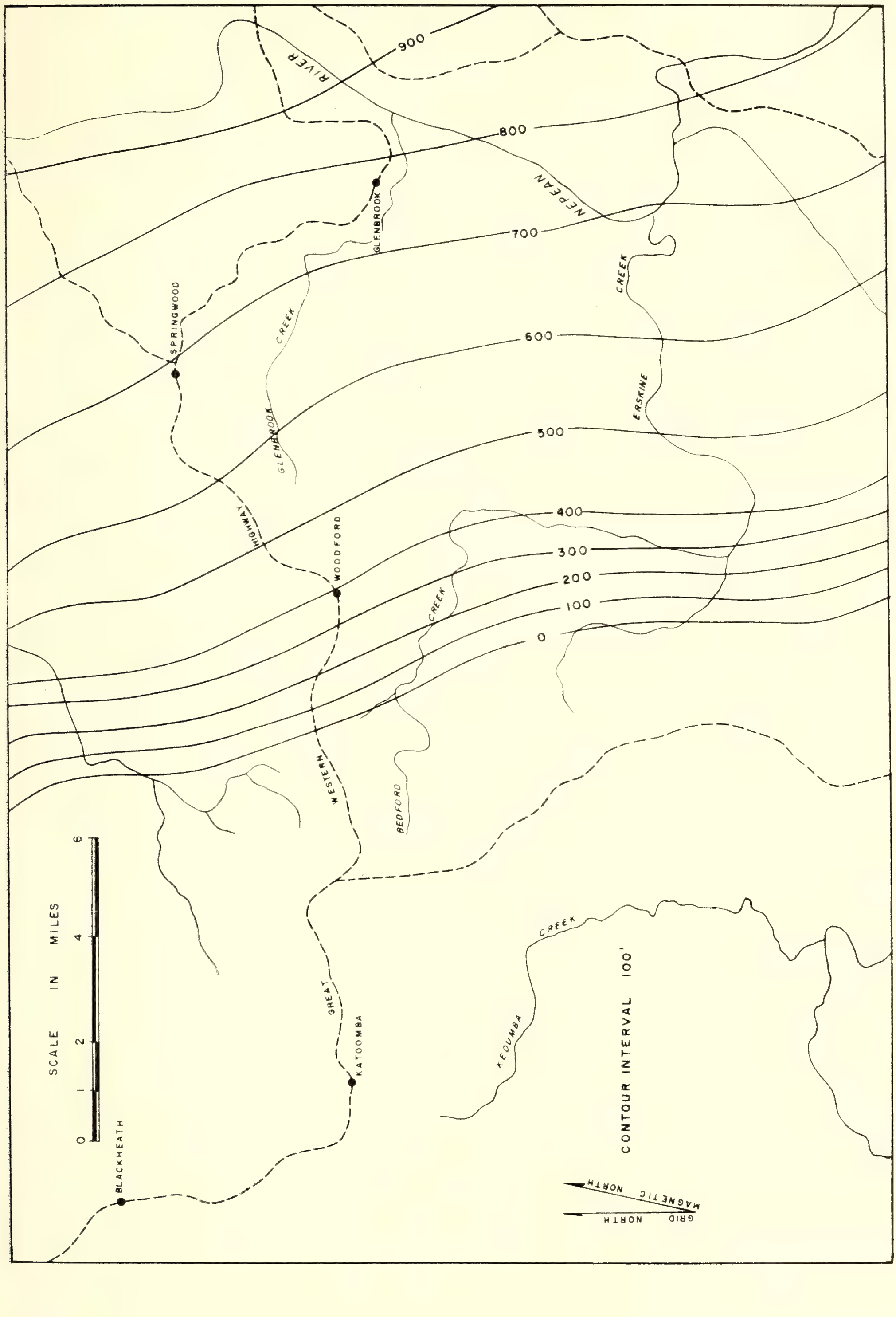

Fig. 6.—Isopach map of Hawkesbury Sandstone.

In the eastern portion of the area under consideration the recognition of the boundary is not difficult. The Burralow Formation is quite distinctive and can be easily recognized in conjunction with a quartz conglomerate horizon at the base of the Hawkesbury Sand-Sandstone. As the western extent of the Hawkesbury Sandstone (Figure 2), just east of Lawson on the Great Western Highway, is approached, the lateral lithofacies change of the Burralow Formation and the disappearance of the conglomerate horizon makes the distinction tenuous.

Hawkesbury Sandstone

Within the study area the Hawkesbury Sandstone attains a maximum thickness of 760 feet in the Mulgoa No. 2 Bore. The Hawkesbury Sandstone is overlain by the Wianamatta Group and underlain by the Burralow Formation of the Narrabeen Group.

With the exception of a few isolated outliers of shales of the Mittagong Formation and the Ashfield Shale (Wianamatta Group), the Hawkesbury Sandstone outcrops at the surface of the plateau from the Lapstone Monocline as far west as Hazelbrook. The Hawkesbury Sandstone thickens rapidly near the western edge of outcrop (Figure 6) and continues to thicken gradually in an easterly direction.

A typical hand specimen of Hawkesbury Sandstone is a white to light brown, medium to coarse-grained sandstone. The sandstone is usually poorly sorted and often iron-stained, although concentrations of iron in the form of bands is uncommon. The matrix of the sandstone is made up of clay minerals, mainly kaolinite, and where iron-staining is absent the sandstone is quite friable. Commonly the sandstone is highly cross-stratified, although thick sequences occur where this is not apparent. Quartz pebbles up to 2 inches diameter commonly occur, particularly toward the base of the sandstone. Lenticular clays and shales, although not common, range in thickness up to 11 feet. Only one occurrence of a siltstone was noted in the Hawkesbury Sandstone, this being in a road cutting on the Great Western Highway west of Linden.

Acknowledgements

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Granitic Development and Emplacement in the Tumbarumba-Geehi District, N.S.W.

(ii) The Massive Granites

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Abstract—The massive granites of the Tumbarumba-Geehi district may be classified into three groups—the Khancoban, Mannus Creek and Dargals granites—on the basis of spatial distribution. The emplacement of Khancoban and Mannus Creek granites post-dates the regional metamorphism of the district although mineralogically and chemically such rocks bear some similarity to the foliated Cooma-type granites that are considered to have been produced in the regional metamorphic processes (Guy, 1969*b*). Chemically such massive granites have high CaO and Na_2O contents and are considered to have developed either at the same time as the foliated granites or by a regeneration of such granitic material.

The Dargals granites are leucocratic with more than 80% normative Q+Or+Ab. It is considered they have migrated far from their position of origin, but may have been produced during the cycle of development of the other massive bodies.

Introduction

Associated with the Ordovician metasediments of the Tumbarumba-Geehi district, N.S.W. (Guy, 1969*a*) are several groups of granitic* bodies. These granites are essentially either foliated or massive, the former—the Cooma-type granites (Guy, 1969*b*)—being associated with the regional metamorphics, while the massive granites post-date the metamorphism, superimposing contact influences on the country rocks. This paper is concerned with the development and emplacement of the massive bodies. These may be subdivided into three groups (viz. the Khancoban granite, the Mannus Creek granite and the Dargals granite) on the basis of spatial distribution (Guy, 1969*a*).

Khancoban Granite

The Khancoban granite is a poorly exposed mass outcropping over some 100 square kilometres. Associated with it is a small body (¼ sq. km.) at Mt. Youngal (G.R. 278.9–134.5)† near Geehi. Contacts with the metasediments are sharp and nearly vertical, while the mass transgresses regional metamorphic zones (Guy, 1969*a*) with a relatively narrow contact aureole developed. Within the body, acid to basic dyke rocks are common, especially in the northern section, as well as north-east trending shear bands being prominent—presumably due to the influence of the Yellow Bog-Khancoban thrust (Cleary *et al.*, 1964). The granite is medium- to coarse-grained with no apparent change in grain size marginally. Although generally massive, a weak but definite north-south foliation is evident, particularly in exposures along the Swampy Plains River. Compared with the Cooma-type granites, there is a notable paucity of aplitic and pegmatitic phases in the mass. Inclusions are limited throughout the body, however, along sections of the Swampy Plains River, clusters of pelitic to psammitic xenoliths have been observed.

Mineralogy and Petrology

Most of the granitic phases in the body are strictly granodiorites, being coarse-grained and more leucocratic than the Cooma-type granites, although biotite is often as high as 12%. The general grain size is 3–5 mm., with alkali feldspars in places to 15 mm. The larger alkali feldspars are optically monoclinic with Δ values generally in range 0·20–0·35, although there is notable variation throughout the body. $2V_x = 75–80°$. These feldspars, frequently poikilitic enclosing plagioclase and biotite, have fine perthite lamellae developed. From the

* The term "granite" as used in this paper includes all acid plutonic rocks unless otherwise stated.

† Snowy Mountains Authority grid reference.

one analysis of the Khancoban granite available (spec. 21817) the bulk composition of the alkali feldspar is estimated at Or_{85-90}, assuming minor amounts of sodium in the micas present. The plagioclases have a bulk composition of An_{35}* with normal zoning from An_{45} to An_{20}. In some sections of the body the average composition of the plagioclases is as low as An_{20}. The plagioclases frequently display an accumulophyric effect (see Plate 1 (*a*)) which is more evident in marginal sections of the body. Such plagioclase clusters are composed of some 20 to 50 small laths, all having approximately the same orientation. The plagioclase also displays "patchy" zoning (*cf.* Guy, 1969*b*) with some areas of the feldspar at slightly different optical orientation to the host. Biotite forms subhedral crystals with Z=dark brown to dark olive-brown and $\gamma=1{\cdot}645$, $2V_x=3$–$7°$. Alteration of this mineral to chlorite and epidote is common. Muscovite is subordinate and where present is in large ragged blades cross-cutting grain boundaries of other phases. Opaque oxides and apatite are accessories.

The small granodiorite body at Mt. Youngal is somewhat similar texturally to the main Khancoban granite. Hornblende is common with X=pale brown-yellow, Y=dark olive-green and Z=sea-green. $2V_x=50$–$55°$ and $Z\wedge c=25°$. Biotite with $\gamma=1{\cdot}650$ and Z=dark yellow-brown or green-brown is also a prominent phase. Plagioclase is somewhat more calcic (average An_{47}) than in the Khancoban granite. Chlorite and epidote are developed at the expense of the mafic minerals.

Inclusions within the Khancoban granite have granoblastic textures with some orientation of micas. Grain sizes average 0·5 mm., with subhedral porphyroblasts of plagioclase to 2–3 mm. The plagioclase (An_{37}) has weak diffuse zoning. Biotite occurs as small flakes with Z=olive-green and $\gamma=1{\cdot}640$. The structural formula of an analysed sample (spec. 21815) is

$$(K_{0\cdot93}\ Na_{0\cdot15}\ Ca_{0\cdot05})(Al_{0\cdot20}\ Ti_{0\cdot08}\ Fe^{3+}_{2\cdot07}\ Fe^{2+}_{1\cdot19}\ Mn_{0\cdot01}\ Mg_{0\cdot98})(Si_{2\cdot74}\ Al_{1\cdot26})O_{10}\ (OH)_2.$$

The pronounced green colour of the biotites is in contrast with those biotites in the granitic phases and those in the inclusions of the Cooma-type granites (Guy, 1969*b*). An analysis of the host rock of the biotite is noted in Table 1 (No. 3).

* Compositions of the plagioclase were determined from the extinction angle $X\wedge(010)\perp[100]$ measured on a universal stage and referred to the low-temperature determinative curves of Bordet (1963).

Table 1

Chemical Analyses, Barth Mesonorms and Modes of Rocks from the Khancoban Granite

Oxide	1	2	3
SiO_2 ..	73·26	70·20	69·82
TiO_2 ..	0·24	0·26	0·90
Al_2O_3 ..	12·79	15·83	13·13
Fe_2O_3 ..	0·47	3·04	0·71
FeO ..	1·90		3·59
MnO ..	0·08	0·08	0·08
MgO ..	0·62	0·75	1·49
CaO ..	2·28	2·87	3·84
Na_2O ..	3·77	2·97	3·31
K_2O ..	4·23	3·57	1·88
P_2O_5 ..	0·03	—	0·07
H_2O^+ ..	0·46	—	0·81
H_2O^- ..	0·06	—	0·13
Total	100·19	99·57	99·76
Q ..	28·64	31·40	34·37
Or ..	23·17	15·75	3·50
Ab ..	34·25	27·15	30·60
An ..	5·55	13·60	15·87
C	—	2·37	—
Bi ..	3·39	9·20	12·72
Act ..	—	—	0·08
Di ..	3·92	—	—
Ap ..	0·05	—	0·16
Ti.. ..	0·51	0·51	1·95
Mt ..	0·49	—	0·76
Quartz ..	36·0	35–40	41·1
K-feldspar	21·0	30–35	—
Plagioclase	34·7	20	38·1
Biotite ..	8·3	7	17·3
Muscovite	—	2	0·8
Chlorite ..	—	—	0·4
Epidote ..	—	1	2·3

1. Spec. 21817, granodiorite, G.R. 281.8–146.0 (3 km. south-east of Khancoban). Anal. B. Guy.
2. Spec. Kh–1, adamellite, Kolbe and Taylor (1966).
3. Spec. 21815, psammopelitic inclusion, G.R. 279.2–139.8 (11 km. south of Khancoban). Anal. B. Guy.

Chemical Data

Only one new analysis is available for the Khancoban granite, and this is presented in Table 1 together with an analysis of an inclusion from the body, and another analysis of the Khancoban granite from Kolbe and Taylor (1966). The granite analyses indicate higher CaO contents than for the Cooma-type granites (Guy, 1969*b*) and Na : K ratios slightly greater than unity. No amphibole has been recorded in the main phase of the Khancoban granite, but normative diopside occurs. The chemical data are summarized in Figs. 1 and 2 (*a*).

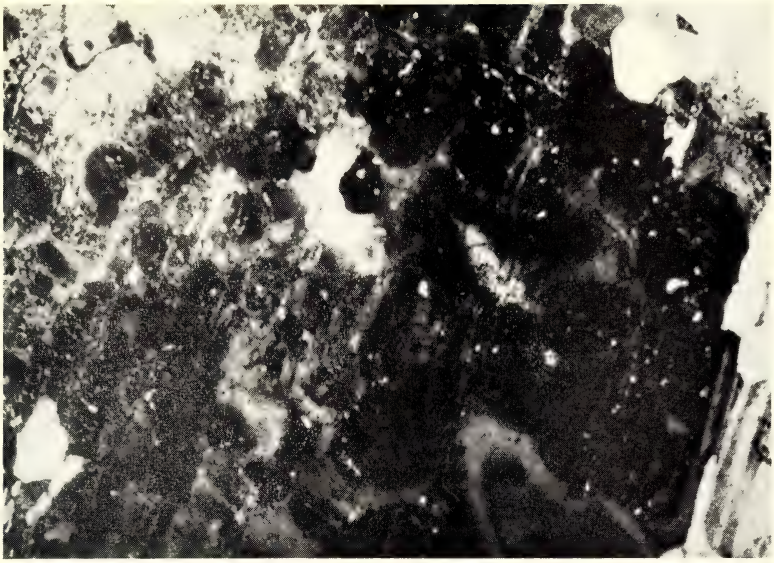

PLATE 1 (*a*)
Section of a plagioclase from Khancoban granite (spec. 21817). The plagioclase consists of numerous small crystals all of which display some zoning. Crystal near extinction position. ($\times$45.)

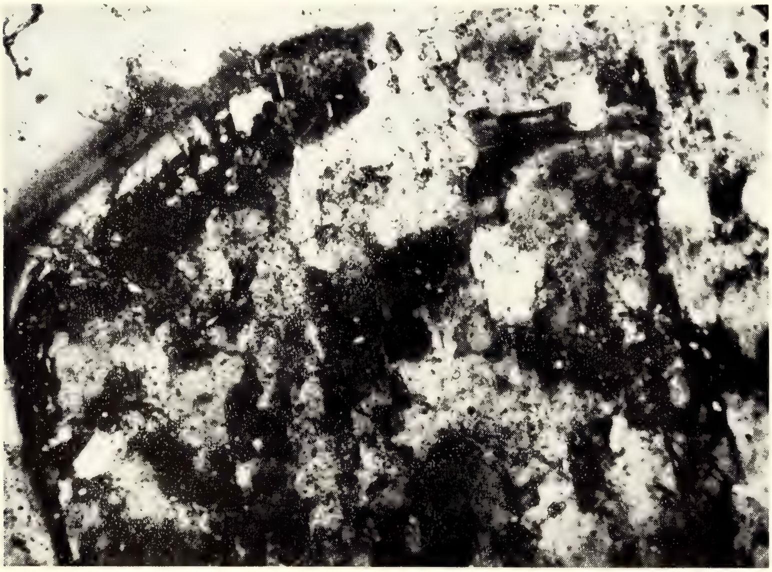

PLATE 1 (*b*)
Section of zoned plagioclase from Munderoo granodiorite (spec. 21840). Note development of patchy zoning. ($\times$45.)

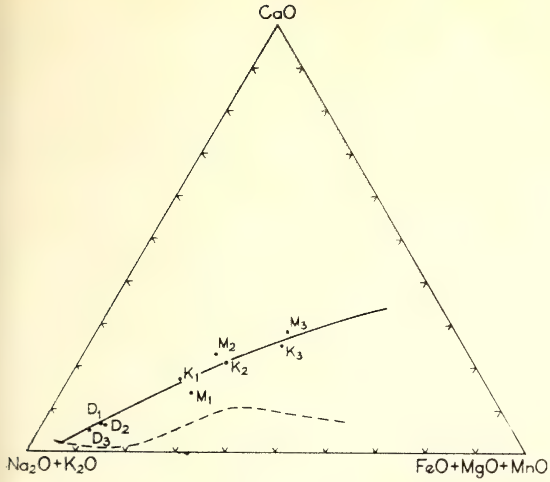

FIG. 1—Plot of Khancoban (K), Mannus Creek (M) and Dargals (D) granites on a $CaO-Na_2O+K_2O-FeO+MgO+MnO$ diagram. Dashed line indicates variation displayed by Cooma-type granites and solid line the variation for Bathurst granites. Murrumbidgee-type granites generally lie between these two curves. (*After* Vallance, 1967.)

It is interesting to compare the analysis of the inclusion with those of the Cooma-type granites since all the inclusions may be derived from rocks similar to the surrounding meta-sediments (Guy, 1969*a*). The Na : K ratio is high (2·67) while the Fe : Mg+Fe ratio is also high (0·56).

Mannus Creek Granite

In the vicinity of Mannus Creek, a small (*ca*. 64 sq. km.) granite complex occurs surrounded by a contact aureole 1·6 km. wide. This complex constitutes the Mannus Creek granite which varies in composition from leucocratic adamellites to hornblende-rich granodiorites. To the west of the area mapped this mass intrudes the Corryong granite. Three major units within the Mannus Creek granite have been recognized (Fig. 3), viz. the Bogandyera granite, the Munderoo granodiorite and the Prison Farm granodiorite. The Bogandyera granite is typically fine- to medium-grained, in places porphyritic in quartz and feldspar. It is usually a granite (*sensu stricto*) or an adamellite. The Munderoo granodiorite is medium-grained with biotite the only mafic phase and is a heterogeneous unit having gradational boundaries with the other units. The attitude of the granite-sediment contact is variable but generally steep, with some shallowly dipping contacts to the north of G.R. 270–170 suggesting the mass exposed may be near the roof of the complex.

All the granitic rocks in this suite are massive and devoid of any directional structures. Apart from some hornblende-rich inclusions in marginal phases of the Prison Farm granodiorite xenoliths are not common, while aplitic and pegmatitic rocks are restricted.

MINERALOGY AND PETROLOGY

The Bogandyera granite has an average grain size of 0·6 mm. with numerous small subhedral phenocrysts mainly of quartz and alkali feldspar. Marginal phases are markedly finer grained. The Munderoo granodiorite has a grain size of 2–3 mm. with occasional phenocrysts of alkali

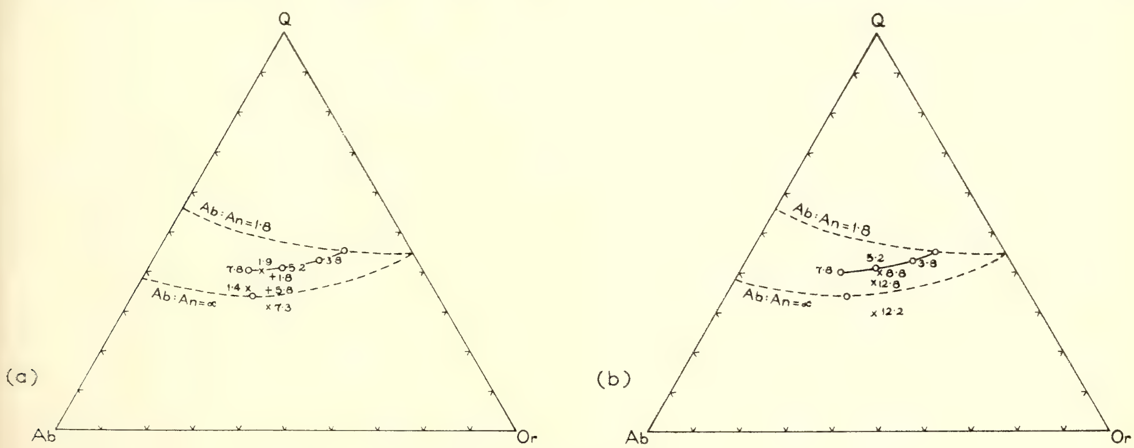

FIG. 2—Projection of Q—Or—Ab—An system at $P_{H_2O}=2{,}000$ bars, indicating cotectic curves for Ab : An ratios of 1·8 and ∞ and the maximum melting points (o) for various Ab : An ratios. (*After* Von Platen, 1965.)
(*a*) Khancoban (+) and Mannus Creek (×) granites, with Ab : An ratios indicated.
(*b*) Dargals (×) granites with Ab : An ratio indicated.

TABLE 2

Chemical Analyses, Barth Mesonorms and Modes of the Mannus Creek Granites

Oxide	1	2	3
SiO_2 ..	71·68	70·60	65·49
TiO_2 ..	0·47	0·30	0·59
Al_2O_3 ..	13·06	14·75	14·69
Fe_2O_3 ..	0·70	0·59	1·37
FeO ..	2·51	2·13	4·13
MnO ..	0·10	0·12	0·13
MgO ..	0·85	0·82	1·92
CaO ..	1·99	2·95	4·79
Na_2O ..	3·92	3·21	3·07
K_2O ..	4·59	3·28	2·79
P_2O_5 ..	0·09	0·10	0·10
H_2O^+ ..	0·39	0·73	0·87
H_2O^- ..	0·05	0·07	0·04
Total	100·40	99·65	99·98
Q ..	24·58	31·87	24·83
Or ..	25·05	15·28	10·07
Ab ..	35·45	29·50	28·25
An ..	4·52	13·25	18·48
C	—	1·31	—
Bi ..	3·68	7·31	10·85
Act ..	4·80	—	4·58
Ap ..	0·19	0·21	0·21
Ti.. ..	0·99	0·66	1·26
Mt ..	0·73	0·63	1·47
Quartz ..	27·2	34·6	25·7
K-feldspar	40·0	14·0	2·5
Plagioclase	20·8	38·5	46·8
Biotite ..	6·8	10·8	14·6
Hornblende	4·8	—	10·0
Accessories	0·3	2·2	0·5

1. Spec. 21831, Bogandyera adamellite, G.R. 271.1–167.4 (10 km. north-west of Tooma). Anal. B. Guy.
2. Spec. 21814, Munderoo granodiorite. G.R. 269.0–175.9 (1 km. east of Mannus). Anal. B. Guy.
3. Spec. 21836, Prison Farm granodiorite. G.R. 271.3–173.1 (8 km. south-west of Tumbarumba). Anal. B. Guy.

feldspar and quartz attaining 5–7 mm., while the Prison Farm granodiorite is even-grained (1–2 mm.). Quartz phenocrysts of the Bogandyera granite are ragged and appear somewhat resorbed. The alkali feldspars are generally optically triclinic with Δ values $>0{\cdot}50$. The bulk composition of the feldspars, as estimated from modal and chemical data, and assuming compositions for the micas, is estimated to be in the range Or_{55} to Or_{75}. This is exclusive of the Prison Farm granodiorite ; it contains only minor quantities of this feldspar. Fine string perthite lamellae may be present in these rocks. Plagioclases are subhedral with normal euhedral zoning. Granitic members of the complex have plagioclases from An_{35} to An_{20}, while in granodioritic phases the plagioclases have cores of An_{45} and occasionally An_{65} (*cf.* Snelling, 1960, p. 194). As noted in the Khancoban granite, some plagioclases display an accumulophyric effect, with patchy zoning also developed (Plate 1 (*b*)). Biotite is present as ragged grains with Z=dark olive-brown (nearly opaque) and $\gamma=1{\cdot}650$. This mica is often associated with, and sometimes replaces, hornblende. Hornblende is euhedral to subhedral but in the Bogandyera granite occurs as small ragged grains exhibiting a glomerophyric texture. All hornblendes have X=light brown, Y=medium brown-green, and Z=blue-green, with zoning from a brown core to green margin, $Z^\wedge c=23–25°$, and $2V_x=65°$. Chlorite, epidote and muscovite appear as alteration products, while apatite and zircon are accessories.

Inclusions within this granitic complex are generally restricted to the Prison Farm granodiorite, and consist of quartz, optically monoclinic alkali feldspar, plagioclase (average An_{35}), biotite and hornblende. Most of the phases are similar optically to those observed in the host rocks.

CHEMICAL DATA

Analyses of granitic rocks from this complex are presented in Table 2. Chemical data are summarized in Figs. 1 and 2 (*a*). The group as a whole displays lower SiO_2 and Al_2O_3 contents than the Cooma-type granites but are similar to the Khancoban granite. CaO, N_2O and the Na : K ratio are higher than for the Cooma-type granites. The Munderoo granodiorite shows some chemical similarity to the Cooma-type granites (but compare Fig. 1). It may be significant that mineralogically and texturally (*e.g.* grain size, clustering of micas) the Munderoo and Cooma bodies are not dissimilar. Further field work to the west of the area noted in Fig. 3 may establish significant information regarding the relationship of the Munderoo granodiorite to the Cooma-type granites.

Dargals Granite

The Dargals granite outcrops over some 230 sq. km. and is generally a rather deeply weathered medium-coarse-grained leucocratic granite. Along its western margin, near the Tooma River, a fine-grained variety predominated, in which mafic minerals constitute several percent of the rock. In such cases

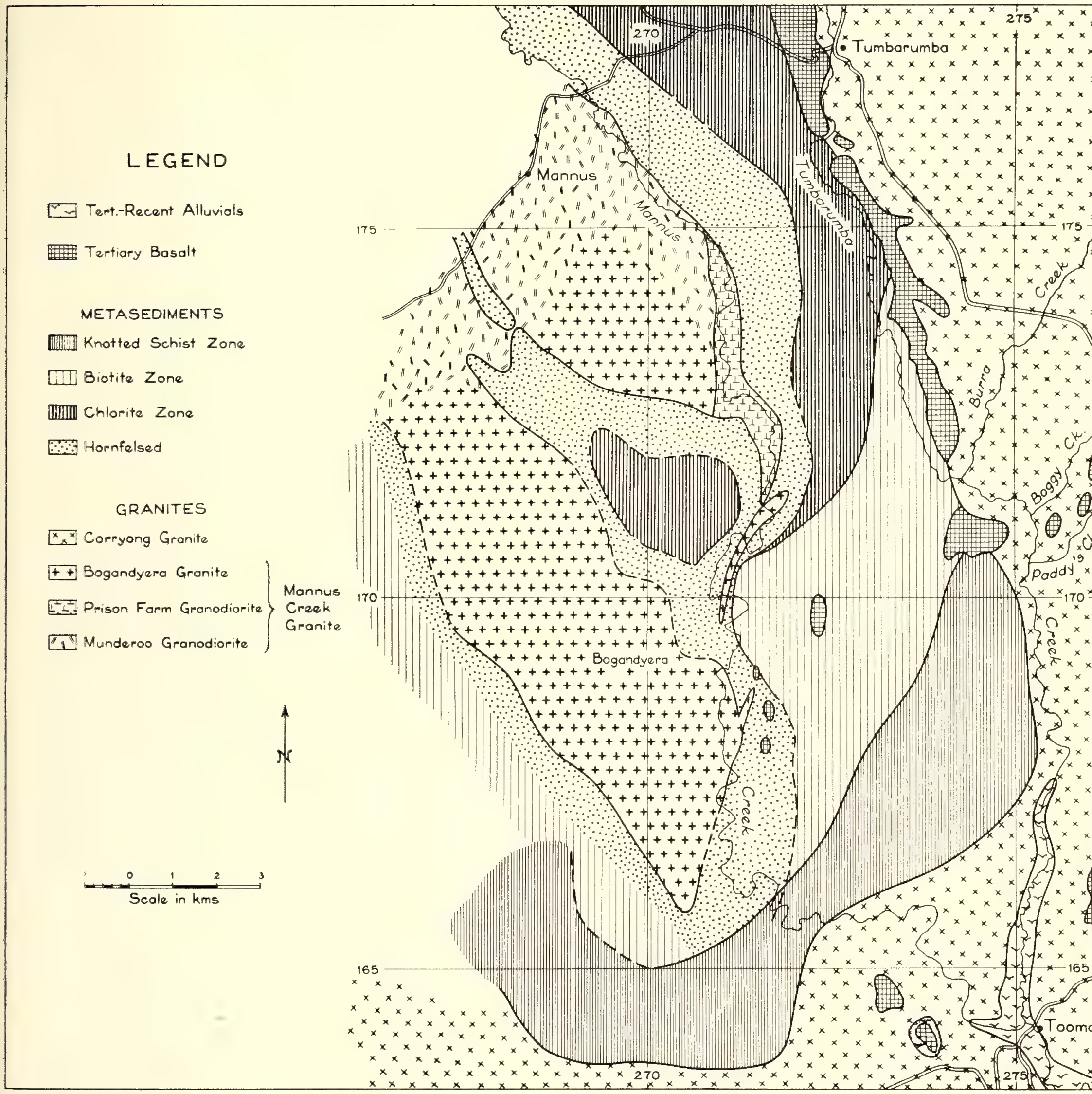

FIG. 3—Distribution of Mannus Creek granites, south of Tumbarumba, referred to S.M.A. grid.

outcrops are more pronounced and a distinctive flora (conifers) is present. In the vicinity of the Big Dargal (G.R. 284.0–155.8) the granite is coarse-grained with megacrysts of subhedral alkali feldspars and occasionally quartz. The Dargals granite is massive throughout and well jointed. Aplitic veins are common, pegmatites less so. Included country rock material is virtually absent, while a prominent exogenous contact zone is developed. Towards the north-east this mass intrudes another granite similar to the Khancoban granite (see Guy, 1969*a*, Fig. 2), however, no detailed examination of this area has been made. The Pine Mountain granite and the Mt. Mittamatite granite (Edwards and Easton, 1937) some 25 km. to the west of the Dargals granite are remarkably similar mineralogically and chemically to the Dargals granite. Small masses at the Granite Knob (G.R. 286.0–114.0) and at Biggera (G.R. 271.0–144.0) may belong to this group.

Mineralogy and Petrology

The medium-grained phases of the granite have an average grain size 2–3 mm., while finer sections average 1·0 mm. Perthitic alkali feldspars are common as subhedral megacrysts up to 5 mm. Δ values average 0·25 for small grains and 0·40 for larger grains, the latter with $2V_x=70°$. Assuming that the micas contain no sodium and that the alkali feldspars contain about 4% An, the composition of these feldspars may be estimated as Or_{80}, from modal and chemical data. Biotite is ragged with numerous small crystals occurring near the ends of, and having the same optical orientation as the larger laths. For these micas Z=dark olive-brown and $\gamma=1·657$. In the porphyritic granite clots of biotite occur (up to 5–6 mm.). These clots are commonly constituted of two varieties, one with Z=dark red-brown and with pleochroic haloes around zircon crystals inclusions, the other with Z=mid-green. The latter biotite appears to replace the red-brown biotite. Accessory minerals in the granite include opaque oxides, apatite, zircon and fluorite.

Chemical Data

Two rocks from the main Dargals granite have been analysed. The data are presented in Table 3 with an analysis from Kolbe and Taylor (1966). This group of rocks is characterized by high SiO_2 and low total iron, MgO and CaO reflecting the paucity of mafic constituents. Total alkalis are high while the Na : K ratio is near unity. These granites have a high oxidation ratio compared with other granitic suites in the Tumbarumba-Geehi district. Chemical data are summarized in Figs. 1 and 2 (*b*).

Table 3

Chemical Analyses, Barth Mesonorms and Modes of the Dargals Granite

Oxide	1	2	3
SiO_2 ..	77·02	76·74	75·37
TiO_2 ..	0·10	0·01	0·06
Al_2O_3 ..	12·02	12·53	13·8
Fe_2O_3 ..	0·61	0·33	0·87 (Fe₂O₃ + FeO)
FeO ..	0·61	0·92	
MnO ..	0·06	0·07	0·06
MgO ..	0·23	0·18	0·086
CaO ..	0·65	0·65	0·50
Na_2O ..	3·63	3·35	3·65
K_2O ..	4·79	4·79	4·71
P_2O_5 ..	0·01	0·03	—
H_2O^+ ..	0·41	0·48	—
H_2O^- ..	0·09	0·10	—
Total	100·23	100·18	99·11
Q ..	34·30	35·40	33·27
Or ..	27·70	27·22	26·83
Ab ..	33·00	30·55	33·05
An ..	2·40	3·15	2·30
C	—	0·71	2·14
Bi ..	1·68	2·56	2·27
Ap ..	0·14	0·05	—
Ti.. ..	0·15	0·03	0·15
Mt ..	0·64	0·34	—
Quartz ..	39·2	36·0	45
K-feldspar	30·4	40·2	15
Plagioclase	27·7	19·7	35–40
Biotite ..	2·4	4·0	2
Accessories	0·2	0·1	1

1. Spec. 21821, adamellite. G.R. 283.5–152.5 (9 km. north-east of Khancoban). Anal. B. Guy.
2. Spec. 21827, granite. G.R. 280.0–158.9 (12 km. south-east of Tooma). Anal. B. Guy.
3. Spec. Ja–1, leucogranite. Kolbe and Taylor (1966).

Discussion on the Origin of the Granitic Rocks

It is not uncommon to find an association of granite types in south-east Australia and it has been claimed by Browne (in David, 1950) that such rocks may be classified into one of the following groups: (i) Ordovician (gneissic granites associated with regional metamorphics), (ii) Silurian (foliated granites with little meta-morphic influence), and (iii) post-Silurian (massive granites). Joplin (1962) has postulated that granitic rocks cannot be assigned to definite orogenic periods on the characteristics suggested by Browne. She claims that the granitic rocks of south-east Australia may be classified

according to their position in the Tasman geosyncline which influenced eastern Australia during the Palaeozoic (see Packham, 1960). Joplin correlates granitic type with time, place and tectonic development in relation to the orthogeosyncline, and also to " intensity of movement during emplacement " (*cf.* Read's 1955 " granite series "). Vallance (1967) has also recognized granitic groups in south-east Australia and refers to such as " Cooma-type ", " Murrumbidgee type " and " Bathurst type ". He has pointed out that each group of granites displays markedly different chemical characteristics, and this may be illustrated when analytical data are plotted on a

" $CaO-Na_2O+K_2O-FeO+MgO+MnO$ (wt. %) "

diagram. Vallance suggests that the relatively high CaO contents of the Murrumbidgee and Bathurst type granites may be related to a varying and locally increasing (perhaps through vulcanism) basaltic component of the crust during geological time. This explanation would not be applicable to the various granitic types of the Tumbarumba-Geehi area as all such bodies are at present localized in a non-volcanic Ordovician terrain. However, it is possible that the massive granites have originated at greater depths than the Cooma-type granites, possibly in sections of the crust adjacent to basaltic rock types.

Several salient points may be emphasized concerning the relationship of the massive granites in the Tumbarumba-Geehi area. The Khancoban and the Mannus Creek granites bear some similarity to the Cooma-type granites, while the Dargals granite and the Pine Mountain granite (Edwards and Easton, 1937) are petrographically and chemically distinct. Discussion on this latter group is deferred (see p. 156). The Khancoban granite displays a weak but discernible secondary foliation yet clearly is not directly connected with the regional metamorphism, superimposing some contact influence on the country rock. This granite, then, probably post-dates the foliated Cooma-type granites, but may have been emplaced while the regional stress field was still active. The petrographic similarity of the Mannus Creek, Khancoban and Cooma-type granites is evident in that the plagioclases have calcic cores and patchy zoning. Chemically these massive granites differ from the Cooma-type granites in that the former have higher CaO and Na_2O contents. Total iron and magnesium contents do not differ markedly (*cf.* Snelling, 1960 ; Vallance, 1953).

The possibility that the massive granites have developed either as a continuation of the regional processes involved in the formation of the Cooma-type granites or a later regeneration of " Cooma-type material " must be examined. Some light may be shed on the problem by the investigations of Von Platen (1965) on the system Q—Or—Ab—An at $P_{H_2O}=2000$ bars. Although recent studies by Weill and Kudo (1968) have placed some serious doubt on the validity of the minimum melting points in this system, as determined by Von Platen, the latter author's result may indicate satisfactorily the trend of a minimum melting point with variation in Ab : An ratio. In an explanation of the development of the Cooma-type granites, it was suggested (Guy, 1969*b*) that such rocks formed by (*a*) accumulation of CaO in high-grade metasediments together with a segregation into quartzo-feldspathic and mica-rich sections, and (*b*) accumulation of Na_2O coupled with a breakdown of micas resulting in the formation of alkali feldspars. It was suggested that not all Cooma-type granites had undergone to the the same degree the processes outlined. Those granites which had undergone both (*a*) and (*b*) processes lay in a field on the " Q-side " of the cotectic in the system Q—Or—Ab—An, while those in which there had been limited breakdown of micas lay on the " plagioclase side " of the cotectic. It may be noted that the distribution of the massive granites is well into the plagioclase field. Thus if the Khancoban and Mannus Creek granites represent highly mobilized metasediments or regenerated Cooma-type granites, then it is unlikely that such rocks would have undergone stages (*a*) and (*b*) outlined above for the Cooma-type granite development, as fluid or " host-rock " phases would tend to be in the " Q-field ". However, such massive granites have higher CaO and Na_2O contents than the foliated granites, hence a possible sequence of events for the formation of the former granites could be (1) accumulation of CaO and segregation into quartzo-feldspathic and mica-rich sections, (2) mobilization of less refractory portions, (3) accumulation of Na_2O in this less refractory section. Of course such segregation in step (1) would not be complete. Kolbe and Taylor (1966) have suggested that the foliated and massive granodioritic rocks from south-east Australia have arisen through (?) complete melting of sedimentary rocks of " Ordovician clay-rich psammopelites with more normal geosynclinal greywackes and shales ".

Although present studies (Guy, 1969*a*) suggest that " normal greywackes and shales " are not common in the sequence—most rocks having relatively high $K_2O:Na_2O$ ratio and high

alumina contents—the geochemical data presented by Kolbe and Taylor is compatible with the proposed process of granitic development.

The Khancoban and Mannus Creek granites bear some mineralogical similarity to the Murrumbidgee granites, although chemically some may be similar to Bathurst granite types (see Fig. 2). Other investigators have suggested a somewhat similar origin of other Murrumbidgee type granites from south-east Australia. For instance, Vallance (1953) indicates that the massive to foliated Ellerslie and Wondalga granites may have arisen partly through " a certain ' rejuvenation ' of the earlier granitic material ". Snelling (1960) has concluded that some of the acid phases of the Murrumbidgee batholith represent the primary magma type with which there had been contamination to produce the " contaminated granites " of the Murrumbidgee batholith.

The process of development of the Khancoban granite implies that mica-rich phases may develop as a by-product of granitic formation. This may also have undergone a process of sodium enrichment and some of the inclusions in the Khancoban granite (Table 1, No. 3) may be chemically similar to such a by-product. Some of the abundant dyke rocks (Joplin, 1958) of dioritic composition occurring throughout the Snowy Mountain region of N.S.W. also may be a result of such granitic development.

The Dargals and Pine Mountain granites are examples of the " leucogranites " of Kolbe and Taylor (1966) that contain significantly more than 80% Q+Or+Ab. The two analyses (Table 3 (1 and 2)) of the Dargals granite plot near the cotectic line for a specified Ab : An ratio in the system Q—Or—Ab—An (Von Platen, 1965). It is possible that such rocks have been largely fluid at some stage during their development and hence may have migrated far from their position of origin. There is no evidence to suggest any substantial modification of their composition through assimilation of other rock types. Such massive leucogranites may have developed through mobilization of the low temperature melting fraction of the other (and older) granitic suites examined.

Acknowledgements

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A Solar Charge and the Perihelion Motion of Mercury

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Abstract—The effect of a possible net solar charge on the perihelion motion of Mercury is examined by using non-relativistic mechanics and by using the Reissner-Nordström metric of general relativity.

(1) Introduction

Bailey (1960*a*, 1960*b*, 1960*c*, 1965) gave explanations of a number of astrophysical and terrestrial phenomena by postulating the presence of a net electric charge on the sun, on other stars, and on planets; two possible sources for such a charge were suggested. It is thus of interest to discuss the possible effect of a solar charge on the motion of the perihelion of Mercury.

General relativity appears to account with an accuracy of about 1% (Dicke and Goldenberg, 1967) for the observed residual advance of the perihelion of Mercury left after planetary perturbations have been accounted for. Various alternative or supplementary explanations have been suggested from time to time, both before and after the advent of general relativity. For example, it has been suggested (Dicke and Goldenberg, 1967) that some (perhaps 8%) of the observed residual is due to solar oblateness, thus threatening the agreement between general relativity and observation; agreement with theory is then restored by postulating a long-range scalar field. Non-relativistic explanations were discussed by Gerjuoy (1956); one of these involves an electric charge on the sun and is considered in Section (2) of this note.

If the sun has a net charge of sufficient magnitude, space-time about it will be represented in general relativity by the Reissner-Nordström metric rather than by the Schwarzschild metric normally used: space-time is modified by the charge, which thus exerts a gravitational effect in addition to purely electromagnetic effects. Perihelion motion in this case is considered in Section (3).

(2) The Non-relativistic Effect

Suppose that the sun is a sphere with a net electrostatic charge Q e.s.u. distributed symmetrically about its centre, and that Mercury can be regarded as an uncharged conducting sphere; the charge on the sun induces a dipole in Mercury. Since the distance r from the sun to Mercury is much greater than both the radius of the sun and the radius a of Mercury, the force on the planet becomes

$$F(r) = -\frac{GM_1M_2}{r^2} - \frac{2f^2a^3Q^2}{r^5}. \quad \ldots\ldots (1)$$

Here G is the gravitational constant, while M_1 and M_2 are the masses of the sun and of Mercury. The factor f, where $0 \leqslant f \leqslant 1$, allows for partial screening of the solar charge by plasma clouds (Bailey, 1965).

The advance δ of the perihelion in radians per revolution is (Gerjuoy, 1956)

$$\delta = -\pi\left(2 + \frac{r}{F}\,\frac{dF}{dr}\right), \quad \ldots\ldots\ldots\ldots (2)$$

r being taken to be approximately constant. If

$$2\frac{f^2Q^2}{GM_1M_2}\left(\frac{a}{r}\right)^3 \ll 1, \quad \ldots\ldots\ldots\ldots (3)$$

equations (1) and (2) give

$$\delta \doteqdot 6\pi\frac{f^2Q^2}{GM_1M_2}\left(\frac{a}{r}\right)^3. \quad \ldots\ldots\ldots\ldots (4)$$

Substituting numerical values, (3) becomes $f^2Q^2 \ll 20 \times 10^{64}$ and (4) gives an advance of $f^2Q^2 \times 40{\cdot}3 \times 10^{-58}$ seconds of arc per century. With $f=1$, this would agree with the observed residual of 43″ if $Q = \pm 1{\cdot}0 \times 10^{29}$ (Gerjuoy, 1956). The value $-Q = 2{\cdot}2 \times 10^{28}$ e.s.u. (Bailey, 1960*c*) gives, with $f=1$, an advance of $2{\cdot}0$ seconds of arc per century; this may be compared with the effect of the solar oblateness determined by Dicke and Goldenberg (1967), namely $3{\cdot}4$ seconds of arc per century, but has

been found by regarding Mercury as a perfect conductor and by neglecting screening.

(3) The Effect in General Relativity

Under conditions of spherical symmetry, the space-time metric can be written, using spherical polar co-ordinates (r, θ, φ),

$$ds^2 = A(r)dt^2 - B(r)dr^2 - r^2(d\theta^2 + \sin^2\theta d\varphi^2) \quad \ldots\ldots\ldots\ldots\ldots (5)$$

where ds is the space-time interval and t is the time co-ordinate. For a spherically symmetric body of mass M and charge Q, (5) becomes the Reissner-Nordström metric in which (Jeffery, 1921)

$$A = B^{-1} = 1 - \frac{2m}{r} + \frac{GQ^2}{c^4r^2} \quad \ldots\ldots (6)$$

where $m = GM/c^2$. When $Q=0$, A and B reduce to the forms appropriate to the Schwarzschild metric.

Suppose that A and B in (5) can be expressed in the forms (Anderson, 1967)

$$A = 1 - \frac{2m}{r} + \alpha_2\left(\frac{2m}{r}\right)^2 + \ldots \quad \ldots (7a)$$

and

$$B = 1 + \beta_1\left(\frac{2m}{r}\right) + \beta_2\left(\frac{2m}{r}\right)^2 + \ldots \quad (7b)$$

where the coefficient of $1/r$ in (7a) has been chosen to give the Newtonian law of gravitation in the appropriate limit. The advance of perihelion of a planet is then given by (Anderson, 1967)

$$\delta \doteqdot \delta_0 \frac{1}{3}(2 + \beta_1 - 2\alpha_2). \quad \ldots\ldots\ldots\ldots (8)$$

For the Schwarzschild metric, the α's vanish and the β's are all unity; then $\delta = \delta_0$. The factor multiplying δ_0 in (8) depends on the central body only. For the Reissner-Nordström metric $\alpha_2 = Q^2/4GM^2$ and $\beta_1 = 1$, so that

$$\delta \doteqdot \delta_0(1 - Q^2/6GM^2).$$

Hence, for the sun, $\delta \doteqdot \delta_0(1 - 6{\cdot}43 \times 10^{-61}Q^2)$. For example, if $Q = \pm 1{\cdot}2 \times 10^{29}$ e.s.u., δ is reduced by 1% from δ_0.

(4) Discussion

The values for $-Q$ deduced by Bailey were around 10^{28} e.s.u. From the above it would seem that such a charge would probably not have a significant effect on the perihelion motion of Mercury. Thus there is probably no inconsistency between Bailey's theories and the successful explanation of Mercury's motion by general relativity.

Acknowledgement

I thank the referee for correcting the numerical coefficient in (3).

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The Distribution of Eupatorium adenophorum Spreng. on the Far North Coast of New South Wales

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Abstract—*Eupatorium adenophorum* Spreng., crofton weed, has remained a major problem in certain areas on the far north coast of New South Wales in spite of a long continued eradication programme. In some areas the weed had been effectively controlled using mechanical and chemical methods. An analysis of the occurrence of crofton weed with respect to a number of environmental factors revealed that rainfall, tree cover and steepness of land each appeared to influence distribution. It was estimated that there was a 76% chance of the occurrence of a significant infestation in areas which had steep land, no tree cover and an annual rainfall in excess of 70 inches. Inaccessibility of steep land with respect to the normal control measures was considered to be the main factor limiting the progress of crofton weed eradication in the area.

Introduction

Eupatorium adenophorum Spreng., crofton weed, an erect perennial herb, is a native of Mexico. It was first recorded in Australia in 1920 under the name of *E. glandulosum* H.B.K. non Michx. (Blakeley, 1920). The correct identity of the plant was not established until 1938 (Everist, 1967, personal communication). Although eaten by sheep and goats, the plant is unpalatable to cattle, and it spread considerably in the northern coastal dairying areas of New South Wales between 1940 and 1955.

Crofton weed was declared a noxious plant on the far north coast of New South Wales under the Local Government Act in 1943. In spite of an eradication programme by the regional weed control authority, the plant has persisted in a large portion of the area, and in 1967 covered 8·4% of the Richmond-Tweed region in significant density (Auld, 1969*a*). In view of this a detailed survey was designed to define the distribution of crofton weed with respect to a number of environmental factors.

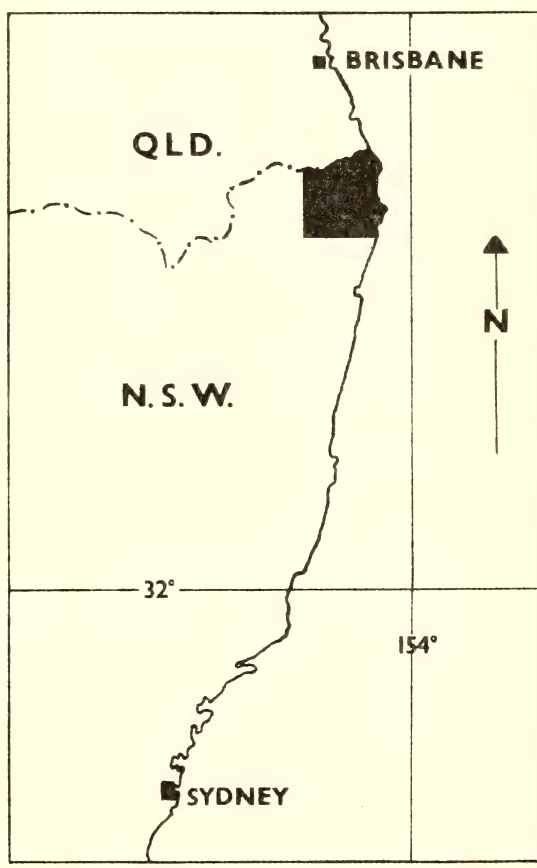

Figure 1.—The shaded area indicates the Richmond-Tweed region on the far north coast of New South Wales, where this work was conducted.
Scale: 1 inch to 100 miles.

Methods

The region (Figure 1) was sampled by a series of belt transects each 5,000 yards wide. The first of these was positioned arbitrarily in an east-west direction, extending from the coastline to the Richmond Range at the western extremity of the region. Similar transects were then placed parallel to this at intervals of 10,000 yards. Each transect was subdivided into 1,000 by 1,000 yard quadrats, each of which

was examined. An infestation of crofton weed was regarded as significant if the total area covered by the perpendicular projection of the aerial parts of the plants exceed 1% of the quadrat area.

The following information was recorded for each quadrat: presence of crofton weed, steepness of land, aspect, tree cover, and average annual rainfall. Each of these factors was divided into a number of classes (Table 1).

The total number of quadrats in each class with or without significant stands of crofton weed was computed. Calculations were also made of the percentage of each class with significant infestations and of the total amount of crofton weed in each class.

Table 1

Observed Incidence of Crofton Weed

Main Factor	Class	Percentage	
		(i) Class Infested*	(ii) Total Crofton Weed Present
Steepness ..	<20°	7	18
	⩾20°	21	82
Aspect	North	15	22
	South	18	32
	East	16	25
	West	13	21
Tree cover ..	Dense	2	1
	Some	11	14
	Nil	21	84
Average rainfall	<50″	6	11
	50–60″	2	5
	61–70″	21	20
	>70″	49	65

* Expected percentage of class infested: 16.

The expected incidence of crofton weed in each class was estimated on the basis of a random distribution (i.e., equal density over the whole region) of the plant. The influence of each factor on distribution was examined for significance by a chi-square test, comparing observed with expected values in each class. A significant effect of a factor on distribution was taken to be indicated by a probability value of less than 0·05, using the data for all classes within that factor.

It has been noted that crofton weed favours frost-free hillside localities such as abandoned banana plantations (Richmond-Tweed Development Committee, 1966), and that the plant is susceptible to frost (Auld, 1969*b*) and usually absent from flat land (Auld, 1969*a*). For these reasons the flat areas of the region were not considered in this survey.

Results

The percentage of each class infested with crofton weed and the percentage of the total amount of crofton weed which occurred in each class is presented in Table 1.

With the exception of aspect, the influence of each factor on distribution was statistically significant ($P<0{\cdot}05$).

The number of infested quadrats with given slope, degree of tree cover and average annual rainfall was determined by summation (Table 2).

Table 2

Effect of Interaction of Steepness, Tree Cover and Rainfall on Distribution

Class Combination			Number of Quadrats with Crofton Weed Present	
Steepness	Tree Cover	Rainfall	Observed	Expected
<20°	Dense	<50″	0	1
		50–60″	1	3
		61–70″	0	0
		>70″	0	1
	Some	<50″	0	7
		50–60″	0	5
		61–70″	0	3
		>70″	5	1
	Nil	<50″	7	23
		50–60″	0	14
		61–70″	9	15
		>70″	16	10
⩾20°	Dense	<50″	0	5
		50–60″	0	22
		61–70″	0	1
		>70″	2	7
	Some	<50″	8	11
		50–60″	1	8
		61–70″	2	2
		>70″	14	4
	Nil	<50″	9	14
		50–60″	7	12
		61–70″	30	19
		>70″	98	20

In the sample taken 10% of the region had the following "environment": (i) nil tree cover, (ii) land equal to or greater than 20° in slope, and (iii) an average annual rainfall exceeding 70 inches per annum. The probability of the occurrence of a significant infestation in this environment was 76%, and indeed 47% of all crofton weed in the area surveyed occurred in such an environment. By including an additional 7% of the region with similar slope and cover, but with a rainfall of from 61 to 70 inches per annum, the occurrence of some 61% of all crofton weed infestations is accounted for.

Discussion

The preference of crofton weed for areas of nil tree cover may well be associated with the fact that its seeds require light for germination (Auld, 1969*b*), while the small size of the seedlings would presumably limit their initial competitive ability under forest conditions.

The observation that this species occurs chiefly in high rainfall areas confirms earlier observations in Hawaii (Ripperton and Hosaka, 1942).

The influence of slope on distribution was marked (Table 2). It is considered that slope has been the major physical factor limiting the progress of crofton weed control in the Richmond-Tweed region because areas where slope is equal to or greater than 20° cannot normally be negotiated by wheel tractors, which renders impractical control by normal mechanical treatments or by high volume herbicide application.

These physical problems render the cost of reclaiming such areas relatively high. In some cases greater returns may be forthcoming from more intensive development of the flatter portions of properties.

The use of crawler tractors rather than wheel tractors is useful in many cases on steep land. However, areas too steep or too rocky to be dealt with in this way still pose a problem. The aerial application of herbicides is not practical because of the danger of drift on to neighbouring horticultural crops, and the results of the attempted biological control of crofton weed have not been very encouraging (Auld, 1969*c*). These areas of rugged terrain, particularly where infestations are scattered, may prove amenable to the use of powder forms of herbicides applied from horseback.

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Chemicals in Food*

J. W. G. NEUHAUS

All food consists of mixtures of chemicals. These are principally proteins, carbohydrates and fats, with minor proportions of phospholipids, sterols, vitamins, minerals and alkaloids, among others. This address is not concerned with the major chemical complexes of food, but rather with the minor components, whether naturally present or deliberately or accidentally added.

Our food embraces many plants and animals which contain chemicals with known toxic properties as natural components. Generally, man has learned to avoid dangerous exposure to these components in his food, but under special circumstances, such as unusual concentration, for example, accidents occur. Acute toxicity, which is frequently recognized and the source subsequently identified, is much rarer than chronic toxicity. The latter only becomes evident after long exposures, and is almost never related to the causative agent.

Natural Compounds in Food

An example of compounds which occur naturally in food and cause chronic toxicity are the goitrogens. It was not until 1928 that the relation between diet and goitre had been established, but it was 1949 before a goitrogen was isolated from Brassicae, an important family of food plants including such vegetables as cabbage, kale and turnips. The compound isolated was l-5-vinyl-2-thiooxazolidone, which owes its activity to its ability to stimulate the secretion thyrotrophin by the pituitary gland. l-5-vinyl-2-thiooxazolidone does not occur free in Brassica seeds but is produced probably from

$$NaOS(O)_2O\text{–}C(SC_6H_{11}O_5){=}NCH_2CH\overset{\displaystyle OH \atop |}{C}HCH{=}CH$$

by enzymatic hydrolysis. Because the compound contained sulphur, investigations have been carried out into the effect of sulphate concentration in the soil on the production of this goitrogen. It was found that high sulphate greatly increased goitrogen production. This compound is not the only goitrogen found in the cabbage family: Langer *et al.* (1962) suggested that the thiocyanate content of cabbage would contribute to its goitrogenicity. However, a daily intake of about 22 lb. of kale or cauliflower would be required to furnish enough thiocyanate to produce a goitrogenic concentration in the blood. Fortunately, much of the activity of these compounds is destroyed by cooking.

Among other substances in food which have some goitrogenic activity attributed to them are non-iodine halides, calcium, arsenic, cobalt, ergothionine, cyanoglycosides and polysulphides. In the case of the non-iodine halides the evidence is slight. In some areas, notably in England, Punjab, South Africa and Soviet Asia, where fluoride occurs naturally in water, the presence of endemic goitre seems to be co-extensive with the fluoride. However, in similar circumstances in Israel, where the iodine intake is adequate, the incidence of goitre is low.

Chemicals with estrogenic activity occur in some foods. Two substances of this type have been identified in soya beans: these are 4′,5,7-trihydroxyisoflavone (genestein) and 4′,7-dihydroxyisoflavone (daidzein). These compounds are weak estrogens. Many plants have shown some estrogenic activity; some of these are carrots, wheat, rice, oats, barley, apples, cherries, plums, and parsley. Because the estrogenic activity of plants is very weak, it is almost impossible to consume sufficient material to invoke an estrogenic response.

Of the toxic chemicals found in food, the cyanogenetic glycosides are one of the most dangerous groups. These compounds, widely distributed in the plant kingdom, yield, on hydrolysis, hydrocyanic acid. Amygdalin, which occurs in the seeds of bitter almond, is perhaps the best known of the cyanogenetic

* Presidential Address delivered before the Royal Society of New South Wales on 1st April, 1970.

glycosides. This compound, on hydrolysis, yields hydrocyanic acid, gentiobiose and benzaldehyde.

The Lima bean, a legume used extensively for food, contains a cyanogenetic glycoside, phaseolunatin, which on hydrolysis yields glucose, acetone and hydrocyanic acid (HCN). It appears that the hydrolysis takes place only if the beans are crushed before cooking. Viehoever (1940) found that the HCN liberated from crushed beans varied from 0·01 0·3%. Serious outbreaks of poisoning from cooked Lima beans have been reported from various parts of the world (Rathenasinkam, 1947; Dunbar, 1920). Experiments with cooked Lima beans raises the possibility that the human body may contain enzymes capable of releasing significant quantities of HCN from cyanogenetic glycosides (the lethal dose of HCN is about 100 mg.).

The occurrence of alkaloids in the plant kingdom is fairly common, and well over 4,000 different alkaloids are known. The humble potato contains an alkaloid, solanine, mainly in the tissue immediately below the skin. The concentration is very high in the green tissue developed prior to shooting. Tea and coffee contain the alkaloid caffeine, and infusions of these plants may contain several per cent. of this alkaloid. The stimulating effect of tea and coffee is due to caffeine, which is said to facilitate mental and muscular effort and to diminish drowsiness; caffeine also has a marked diuretic effect.

A large number of amino compounds, many with high physiological activity, occur naturally in food. Included amongst these are the highly potent amines histamine, tyramine, tryptamine, and 5-hydroxytryptamine (serotonin). Bananas, plantains (sugar bananas), pawpaw and pineapple contain serotonin in concentrations up to 10 mg. per 100 g. of fresh fruit. Even the tomato contains about 0·4 mg. serotonin per 100 g. Aged cheese is a source of physiological amines, e.g. one specimen of Camembert contained 200 mg. tyramine per 100 g. The primary route of detoxification of primary amines is the oxidation to the corresponding carboxylic acid through the agency of the enzyme monoamine oxidase. As might be expected, accidents have been reported when patients were treated with monoamine oxidase-inhibiting drugs. One such accident occurred when a group of patients, receiving the tranquillizer "Parnate" (tranylcyramine), ate some matured cheese. This gave rise to hypertensive crises which were fatal in some cases. The serotonin intake of certain African peoples who use plantains as a major item of diet may reach 200 mg. per day. The high incidence of cardiovascular disease amongst these peoples may be related to the high intake of serotonin.

One of the most important groups of anti-enzymes contained in food is the cholinesterase inhibitors. The cholinesterases occupy a unique position in the animal kingdom, for they are involved in nerve impulse conduction and thus are vital to the well-being of animals. Some edible plants which yield cholinesterase inhibitors are, for example, broccoli, cabbage, pepper, Valencia orange, pumpkin, squash, carrot, strawberry, apple and potatoes. In the case of the potato it appears that the alkaloid solanine may be the cholinesterase inhibitor.

There are many other substances in food which have toxic effects; for example, there is a complicated antagonism between unsaturated fatty acids and carotene.

The foregoing examples should serve to illustrate that food is not necessarily safe.

Natural Additives in Food

Fungi

Bacterial or fungal infections can give rise to toxin in food. For example, *Clostridium welshii*, a spore-forming anaerobic organism, is often the causative organism in food poisoning. A common source of poisoning is chicken salad which has been stored at room temperature for some time before serving. Among the compounds which are formed in food by micro-organisms are a group of substances which can cause fibrous growths. Some of the most important of these compounds are the aflatoxins.

The effect of these substances was first noticed in England when about 100,000 turkey poults died in 1960 from what was then known as "turkey X disease". The disease was soon traced to peanut meal. Subsequently, in 1961, it was found that the infection was caused by a strain of *Aspergillus flavus*, and the toxic substance was named "aflatoxin". The aflatoxins cause serious liver toxic reactions, producing fibrosis and cirrhosis in young Rhesus monkeys. These compounds cause a high incidence of carcinomas in the livers of rats at levels of 1–6 μg. per day. The purified aflatoxins are carcinogenic in the livers of rainbow trout at a level of about 0·08 p.p.m.

Metals

Practically every element in the periodic table can occur either naturally or accidentally

in food. Some metals, like iron and cobalt, are essential for the well-being of animals. Some, such as arsenic and barium, have no known useful function in the diet and are harmful at quite low concentrations. No method is known to avoid metallic contamination of food if the metal occurs in the soil where the crops are grown or where the animals graze. The traces concerned are usually so small that no harmful effects arise from their consumption and it is possible that harmful effects may arise in their absence. Of the trace metals essential for life, copper is an interesting example. Formerly, much of the food processing equipment was fabricated from copper; today stainless steel is the principal metal used. Some years ago there was a spate of complaints of "off" odours and flavours in bottled milk delivered to homes. This problem was traced to the copper content of the milk. Copper, which normally occurs in milk at about 0·15–0·2 part per million, had increased to several parts per million. Investigation revealed that the excess copper was coming from pasteurizers in the milk factory. This milk, on standing in sunlight, very rapidly developed "off" flavours and odours due to the copper greatly accelerating the normal staling processes in the milk fat. These effects are usually masked by bactriological changes producing, amongst other things, lactic acid. Copper is essential for animals because it is involved in haemoglobin formation. Many plants and animals used for food contain traces of copper such that the daily intake is about 2 mg. This is more than sufficient for metobical requirements.

Lead is one of the harmful metals which occurs in traces in practically all foods. These traces are derived from the soil in which the plant grows. Research indicates that some lead may be derived from lead tetraethyl used in motor spirit. As early as 1930, fears were being expressed about the effects of leaded petrol, and the government laboratory of the Departmental Committee on "Ethyl Petrol" found that the average amount of lead inhaled from the air of towns in Great Britain was 0·077 mg. per day. Lead is also a frequent accidental contaminant of food, sometimes from unsuspected sources such as old paint on ceilings slowly chalking or from leadlighted panels in kitchen cabinets.

Substances Deliberately Added to Food

These substances are often referred to as food chemicals, and are often very much safer than chemicals naturally present. Chemical compounds are added to food to achieve one or more of the following aims: to improve the keeping quality, the nutritional properties and the appearance or to improve tastes, and thus consumer acceptability of the food. The substances used fall into three main categories:

(*a*) Complex chemical substances such as proteins extracted from other foods, e.g. casein added in sausages.

(*b*) Naturally-occurring simple substances such as salt, acetic acid and ascorbic acid.

(*c*) Synthesized substances not found in nature, such as antioxidants, emulsifiers, preservatives and colours.

At the Delaney enquiry in 1954 it was stated that there were 704 different chemicals being used in food in the U.S.A. Now the number of chemicals given approval for such use by the Food and Drug Administration of the U.S.A. is about 10,000. Such is American law now, that any new substance proposed as a food additive must not only be safe, but must be proved to be safe, usually by protracted animal feeding experiments. The testing programme of food additives has resulted in some substances being removed from the permitted list on evidence which is so slender that it is almost impossible to find the reason. Fortunately, sodium chloride is one of the substances on the "gras" (*generally regarded as safe*) list, for if it were to be tested under the conditions required, it would fail miserably and be banned in the U.S.A.

Preservatives have been in use from very early times. The process of "salting" or "smoking" fish was perhaps the first preserving process using chemicals. "Smoking", a once popular process, added formaldehyde amongst other things to the meat. Modern preservatives include disodium acetate, which is used to preserve bread (anti-mould), where up to 6 oz. is used per 100 lb. of flour. Benzoic acid, which occurs naturally in cranberries, is used extensively in soft drinks. Benzoic acid has been used in ice to keep fish fresh. It prevents trimethylamine being detected without interfering with bacterial spoilage. This highlights one of the hazards of using chemical preservatives. It is most important that the preservative does not permit the growth of abnormal flora such as pathogens while obscuring spoilage changes.

Other acid preservatives include sorbic acid used to prevent mould growth in baked goods. Sulphur dioxide has been used for a long time as a preservative, especially in beverages, dried

fruits and meats. The action of sulphur dioxide is not clearly understood, but it may inhibit sulphur-containing enzymes. Sulphur dioxide also acts as an anti-oxidant, for it can be used to protect ascorbic acid during the drying of fruit. Unfortunately, sulphur dioxide destroys thiamine in the food treated with it. Mapson *et al.* (1961) reported a 30% destruction of thiamine in sulphite-treated chipped potatoes, and Mallette *et al.* (1946) reported almost complete destruction of the thiamine in cabbage blanched in sulphite solutions, while riboflavin and niacin were unaffected. Another preservative is hydrogen peroxide, which is used to prevent staling of cream. The advantage of this preservative is that the by-products are oxygen and water. Further, excess peroxide can be destroyed by catalase, which can eb inactivated by heat and therefore does not affect further processing.

Fatty foods are susceptible to oxidative changes in the fat molecule with the production of rancid flavours and odours. The autoxidation of fats involves the formation of a free radicle. This process can be catalysed by traces of metals such as copper, 0·05 p.p.m. of which was found to double the rate of oxidation. Once a free radicle is formed, the reaction becomes self-perpetuating, with the regeneration of the free radicle and the production of a peroxide molecule :

$$R^{\cdot}+O_2 = RO_2^{\cdot} \text{ (peroxy radicle)}$$
$$RO_2^{\cdot}+RH = ROOH \text{ (peroxide)} + R^{\cdot}.$$

To slow the rate of autoxidation, compounds like butylated hydroxy anisole and propyl, octyl or dodecyl gallate are used. These compounds can exchange the free radicle with the fat molecule, but because of steric hindrance the free radicle so produced is unable to propagate further free radicle formation. The chain is then terminated by dimerization :

$$\begin{aligned} R^{\cdot}+AH \text{ (anti-oxidant)} &= RH+A^{\cdot} \\ A^{\cdot}+A^{\cdot} &= AA \\ \text{or } A^{\cdot}+R^{\cdot} &= AR \text{ (inactive).} \end{aligned}$$

It is obvious that these processes "use up" the anti-oxidant.

Compounds like glycerolmonostearate and sorbitan or polyoxyethylene fatty esters are used as emulsifying agents. These compounds improve volume and uniformity of flour confectionery. In bread they help to produce a loaf with a softer crumb and somewhat slower staling rate.

The texture of ice-cream and other frozen desserts is dependent, in part, on the size of the ice crystals in the product. The size of ice crystals can be controlled to some extent by the addition of some form of stabilizer. Substances typically used include agar-agar, gelatin, gums and alginates.

A group of chemical compounds commonly used in food are the dyes, the "Coal Tar Colours", so called in an allusion to the early methods of production. There are about 46 separate dyes produced specifically for use in food. Of this number only six are common to 40 or more countries—three reds, two yellows and one unsatisfactory blue. It is almost certain that the permitted lists of each country have been drawn up with the same object in mind ; that is, to protect the ultimate consumer. Unfortunately, a satisfactory list of universally acceptable colours does not exist. The New South Wales list has 23 shades : eight reds, one orange, six yellows, one green, two blues, one violet, three browns, and one black. Some of these dyes contain an azo group and are, according to one school of thought, suspect. The most studied azo dye is 4-dimethylamino-azobenzene, known as butter yellow or methyl yellow. This dye was formerly used extensively in some countries as a food colour. The dye has been shown to be carcinogenic to rats, but strangely enough only when the diet was nutritionally deficient, particularly in riboflavin, which participates in the metabolism to harmless derivatives. There is no firm evidence that any of the food colours have caused any adverse reactions in man.

The chemicals in food which have received the greatest publicity are the residues of pesticides used to control weeds, insects, fungi or plant growth. The use of large quantities of pesticide is usually justified by the need to produce more food. Of the pesticides, D.D.T. has received most attention. Many publications have appeared pointing out the dangers of the accumulation of chlorinated pesticide residues. Some have pointed to the decrease in fertility of some species of sea birds, others have drawn attention to the presence of D.D.T. in the fat of the Weddle seal. With all the spate of literature it is almost impossible to tell whether the reduction in fertility of some sea birds is due to D.D.T. or to some other as yet unidentified cause, or if, indeed, a reduction in fertility has occurred at all. The danger is that chlorinated pesticides may be blamed and the true cause ignored, especially when efforts are being made by some pressure groups to have D.D.T. banned.

The residue position is so emotionally charged that it will be very many years before a truly objective perspective can be obtained; until this time the true position will remain obscure.

The problem with chlorinated pesticides appears to be related to their very long life and the fact that they are fat-soluble. Endrin and dieldrin, in relatively large doses, such as arise from accidental ingestion of toxic quantities, produce epileptic-type spasms and are feared for this reason.

The organic phosphorous insecticides are, generally speaking, much more toxic than the chlorinated compounds because they are cholinesterase inhibitors. The life of these phosphorous compounds is very much shorter, being measured in weeks or days rather than years, which is the rule for the chlorinated compounds. Because of their short life, they present relatively little problems of chronic toxicity. Nevertheless, a major hazard can develop from the use of these compounds. The recommended usage includes a withholding time after application, but the withholding time is almost impossible to police, partly because market and weather conditions may dictate an earlier harvest than was anticipated.

Pesticides are not the only chemicals used in agriculture which cause concern. Some German work has indicated that the humble spinach can be deadly to babies when grown in soils with a high available nitrogen content. The nitrate content of many leaf vegetables is dependent on the available nitrogen in the soil. After harvest and cooking, some of the nitrate may be converted to nitrite. Nitrite is a dangerous substance because it causes slowly reversible changes in the haemoglobin of the blood, thus reducing the oxygen capacity of the blood, which may result in cyanosis and death in severe cases.

With all the problems associated with food, we must eat to live and must consume about 400 g. of food each day. Naturally, each one of us can no longer produce all his own food, and must depend more and more on processed food. Perhaps in time all food will be safe to eat. This I know: the testing of new additives is so rigorous that the danger from this source is much less than that from " natural " food.

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The Occurrence and Significance of Triassic Coal in the Volcanic Necks near Sydney

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ABSTRACT—The breccia pipes near Sydney contain numerous inclusions of coal. Spores have been macerated from some of this material, the microflora obtained being no older than Hawkesbury Sandstone equivalent. The coal both in the breccia pipes and in the peripheral contorted zones is of bituminous rank, which is evidence that it has not been heated above quite modest temperatures.

Introduction

Although David (1896) suggested that the coal in the Euroka Farm breccia pipe was probably derived from the " Hawkesbury Sandstone ", coal fragments in other similar breccia pipes near Sydney have generally been assumed to be of Permian age. New evidence indicates that coal in at least several of these breccia pipes is of Triassic age and is now at a lower position than the strata from which it was derived.

The volcanic necks under discussion are situated in an area extending to about 25 miles north, 43 miles east, and 30 miles south-east of Sydney. Localities are given in the table as Army Grid references for the Sydney Four-Mile Topographic Sheet. Further details on the localities are given by Adamson (1966). Wilshire (1961) has described some of the volcanic necks as layered diatremes. They generally occur as vertical pipes with circular to irregular elongated outcrops ranging in area from a few acres to more than 40 acres. The breccias consist predominantly of altered basaltic fragments, commonly amygdaloidal, set in a matrix of clay and carbonate minerals and scattered quartz grains. They also contain a wide variety of other igneous and sedimentary rock fragments, including coal.

Peripheral Zones in the Pipes

At some localities contorted beds of sedimentary rocks have been exposed between the breccia and the non-deformed country rocks. Coal occurs sporadically in such peripheral zones at Minchinbury quarry and Erskine Park quarry. At an exposure in Minchinbury quarry the contact between the contorted sediments and the wall rock is marked by a small fault. Here the contorted sediments are less deformed and are clearly part of the country rock. The sedimentary beds in the peripheral zones are generally centroclinal.

The coal in the peripheral zones attains a maximum thickness of about one foot. It is a moderately bright humic coal and contains a high proportion of exinite, especially in the form of leaf cuticle. This abundance of leaf cuticle is not typical of the Permian coals of the Sydney basin, but is much more characteristic of some Triassic coals—such as the Ipswich coals of south-eastern Queensland (Cook and Taylor, 1963). The maximum reflectance of the vitrinite in the contorted sediments lies within the range 0·87–0·97%. These low reflectance figures suggest maximum temperatures probably of less than 100° C. Deformation in the contorted sediments has resulted in fragmentation of the coal, with rotation of the fragments and their subsequent bonding by " pressure welding ". The optical anisotropy of these fragments, however, is related to the original direction of bedding, indicating that the fragments were not plastic during deformation. This also indicates that the coal was subject to a maximum temperature well below 350° C., at which the vitrinite would become appreciably plastic (Brown, Taylor and Waters,

1965). It also suggests that this coal may have been of sub-bituminous or bituminous rank at the time of deformation.

An abundant, well-preserved, microflora has been extracted from the coal in the contorted sediments. It consists of *Alisporites* spp., *Aratrisporites* spp., *Cadargasporites senectus*, *Converrucosisporites cameroni*, *Dictyophyllidites mortoni*, *Cycadopites nitidus*, *Kraeuselisporites differens*, *Lycopodiumsporites* sp., *Microreticulatisporites* sp., *Neoraistrickia taylori*, *Nevesisporites limatulus*, *Polypodiisporites ipsviciensis*, *Punctatisporites* spp., *Punctatosporites walkomi* and *Verrucosisporites* spp. In particular, the presence of *Cadargasporites senectus* in association with *Kraeuselisporites differens* and *Nevesisporites limatulus* indicates that the microflora is no older than the equivalent of the Minchinbury Sandstone, i.e., it is of M.–U. Triassic age.

Coal Fragments in the Breccias

Every breccia pipe in the Sydney region so far examined by the writers contains sparsely and unevenly distributed coal fragments. Although the coal fragments in the breccias are now of approximately the same rank as the coal in the peripheral zone (i.e., high volatile bituminous), most of these fragments appear to represent former single pieces of wood. The coalified wood fragments are generally elongated and range in length from about one millimetre to some tens of centimetres. They are commonly surrounded by rims up to several millimetres thick of calcite containing euhedral prismatic crystals of quartz. The presence of the rims suggests that the fragments of woody coal have shrunk, usually to between one-half and three-quarters of their former volume. Also, the even thickness of the rims around fragments of banded coal suggests that they have shrunk uniformly to some 80–90% of their former volume.

A well-preserved microflora has been extracted from two coal specimens from the Hornsby breccia. It consists of *Alisporites* spp., *Aratrisporites* spp., *Cycadopites nitidus*, *Duplexisporites gyratus*, *Granulatisporites minor*, *Kraeuselisporites pallidus*, *Neoraistrickia taylori*, *Osmundacidites* spp., *Pilasporites plurigenus*, *Polypodiisporites ipsviciensis*, *Punctatisporites* spp., *Punctatosporites walkomi*, *Verrucosisporites* sp., and *Vitreisporites pallidus*. The microflora is dominated by *Kraeuselisporites pallidus* and *Pilasporites plurigenus* and represents a particularly specialized assemblage reminiscent of some of the microfloras extracted from Ipswich coals of Triassic age. The presence of *Duplexisporites gyratus* indicates that the microflora is certainly no older than middle Hawkesbury Sandstone equivalent.

Localities of Pipes and Reflectances of Coal Specimens

	Pipe	Locality		Maximum Reflectance of Vitrinite at λ of 527 nm.
		Army Grid Reference	Adamson's (1966) Reference	
Fragments in Breccias	Hornsby Quarry	409,837	4	0·98–1·26
	Minchinbury Quarry	383,824	5	0·84–0·92
	Erskine Park Quarry	379,822	6	0·85–1·09
	Richardson's Farm	382,821	31	0·80–0·86
	Norton's Basin	361,817	35	0·76–1·04
	Davidson's Quarry	383,835	7	0·81–0·96
	Bulls Hill	389,818	32	0·92–0·97
	Patonga	428,859	—	0·73–1·78*
	Fitzpatrick's First Quarry	391,824	28	0·93–0·98
	Gilligans Road	405,840	21	0·66–0·91
	Campbelltown	377,786	36	1·80–1·90†
	Bloodwood Road	407,852	14	0·78–0·94
Peripheral Zones	Minchinbury Quarry	383,824	5	0·76–0·96
	Erskine Park Quarry	379,822	31	0·82–1·04

* The material of higher reflectance shows textural evidence of heat alteration, presumably by the basaltic intrusion which occurs in the pipe.

† A single specimen from vicinity of intrusion which appears to have caused abnormal reflectance.

A well-preserved microflora also has been extracted from coal in the Patonga breccia. It consists of *Acenthotriletes* sp., *Alisporites* spp., *Cycadopites nitidus*, *Cycadopites* sp., *Dictyophyllidites mortoni*, *Kraeuselisporites differens*, *Monosulcites* sp., *Neoraistrickia taylori*, *Osmundacidites* spp., *Pilasporites plurigenus*, *Polypodiisporites ipsviciensis*, *Punctatisporites* spp., *Vitreisporites* sp., and *Circulisporites parvus*. The microflora is dominated by *Alisporites* spp. and *Neoraistrickia taylori*. The acritarch *Circulisporites parvus* is also particularly common. Overall, the assemblage is similar to the microfloras described previously, the presence of *Cycadopites nitidus* indicating that it is no older than Hawkesbury Sandstone equivalent.

The coal fragments from which spores have been extracted are petrologically very similar to the coal in the peripheral contorted zones at the margins of the Erskine Park and Minchinbury pipes.

A comparison of coaly material from the various breccia pipes and the peripheral zones is given in the table. The reflectances of woody and banded coals fall within the same range, although woody coal is in general isotropic and banded coal is anisotropic.

The table shows that the maximum reflectances of vitrinite from coal in the peripheral zones mostly lie within the same range as those from the breccias. All of the values are significantly lower than those for Permian coal in the northern part of the Southern Coalfield, N.S.W., where the maximum reflectance values so far recorded lie between 1·35% and 1·51%.

Discussion

The rank of the coaly material at the time of its incorporation in the breccia poses something of a problem. The properties of fragments of banded coal in the contorted sediments and, probably, in the breccia also, point to the coal having been at or close to the bituminous coal stage of rank. However, this would appear to conflict with available stratigraphic evidence, which suggests that an insufficient thickness of sediments could have overlain a Wianamatta-age coal at the time the breccia was formed.

All microfloras recovered from the coal to date indicate a specific Triassic age for the breccia formation. This is consistent with the observation that volcanic detritus is the dominant component of Wianamatta Group sediments above the Ashfield Shale, suggesting contemporaneous volcanic activity. There is also some evidence that at least one of the volcanoes (Richardson's Farm) has been buried by Wianamatta sediments.

None of the coal shows evidence of profound thermal alteration, which, had it occurred, would have been indicated under the microscope by changes in the optical and structural properties of the vitrinite and exinite minerals. In the same way spores are excellently preserved after maceration. The banded coal fragments have undergone very little deformation while in the breccia, and the only effects attributable to their incorporation are shrinkage, as indicated by rims, and a possible slight increase in rank. Some of the woody fragments of coal in the breccia have deformed plastically, apparently prior to a fairly uniform shrinkage. These effects of shrinkage and rank are probably the result of slight increases in temperature. The low temperature indicated is consistent with the hypothesis that cooling may have occurred as a result of adiabatic expansion. This is also suggested by the glassy nature of the basaltic fragments (though much of this is now altered) and by the occurrence of tiny vesicles in the same material.

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The Coolac-Goobarragandra Ultramafic Belt, N.S.W.

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Abstract—The Coolac-Goobarragandra ultramafic belt, in the south-east of New South Wales, delineates a steeply inclined sheet of peridotite and serpentinite 56 km. long and up to 2 km. thick, which occupies a tectonic zone between western Lower Palaeozoic beds and the Siluro-Devonian Burrinjuck granite mass on the east.

Petrogenetically critical components of the principal rock association of the belt include predominant cataclastic harzburgite which encloses autolithic Cr-rich and Al-rich chromitite pods, and gabbro-derived garnet-vesuvianite rodingite veins and rootless dykes which penetrate both the harzburgite and the chromitites. A magmatic gabbro-wehrlite complex of doubtful status occurs in the north.

The whole association is tentatively interpreted as a mush- and tectonically-re-emplaced and partly re-intruded abyssal complex in which a quasi-stratiform configuration of harzburgitic mush and basic magma components at depth was to some extent reproduced but also telescoped at a shallow crustal level.

1. Introduction

Ultramafic rocks in south-eastern New South Wales were referred to briefly by Carne (1892), Card (1896), Jaquet (1896), Raggatt (1925, 1936), Benson (1926), Brown (1929), David (1950), Adamson (1957), Joplin (1962) and Golding (1961–1967). The rocks occur at intervals within a broad linear zone trending south-south-east from Girilambone, near Nyngan ; through Fifield, Arramagong and the Coolac-Gundagai district to Tumut Pond, near Kiandra (Rayner, 1961) ; over a distance exceeding 300 miles (Figures 1 and 2). The terms Gundagai Serpentine Belt (Rayner, 1961), Lachlan Serpentinite Belt (Fraser, 1967) and Girilambone-Kiandra Belt (Golding and Bayliss, 1968) have been proposed for the whole zone.

The Coolac-Goobarragandra ultramafic belt is the largest of the exposed subsidiary units within the Girilambone-Kiandra Zone, and its size and accessibility recommend it as a type unit in studies of the whole zone.

Field observations in the period 1961–1965, the examination of some 1,200 thin sections (including those of Veeraburus (1963) and Fraser (1967)) and unpublished studies of the chromitites (Golding, 1966) have contributed to the writer's conception of the belt.

This paper summarizes the available data on the setting and petrography of the belt, draws attention to problematic features requiring

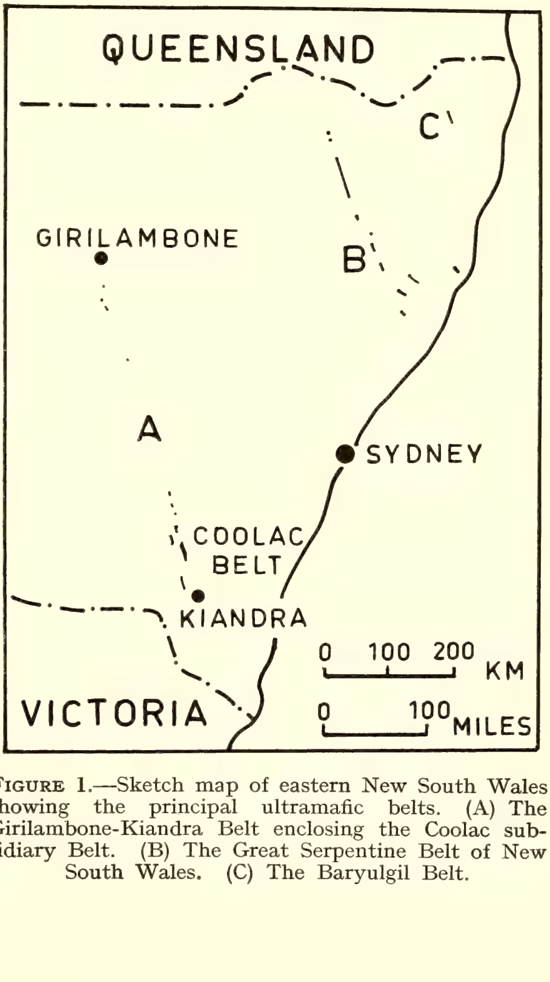

Figure 1.—Sketch map of eastern New South Wales showing the principal ultramafic belts. (A) The Girilambone-Kiandra Belt enclosing the Coolac subsidiary Belt. (B) The Great Serpentine Belt of New South Wales. (C) The Baryulgil Belt.

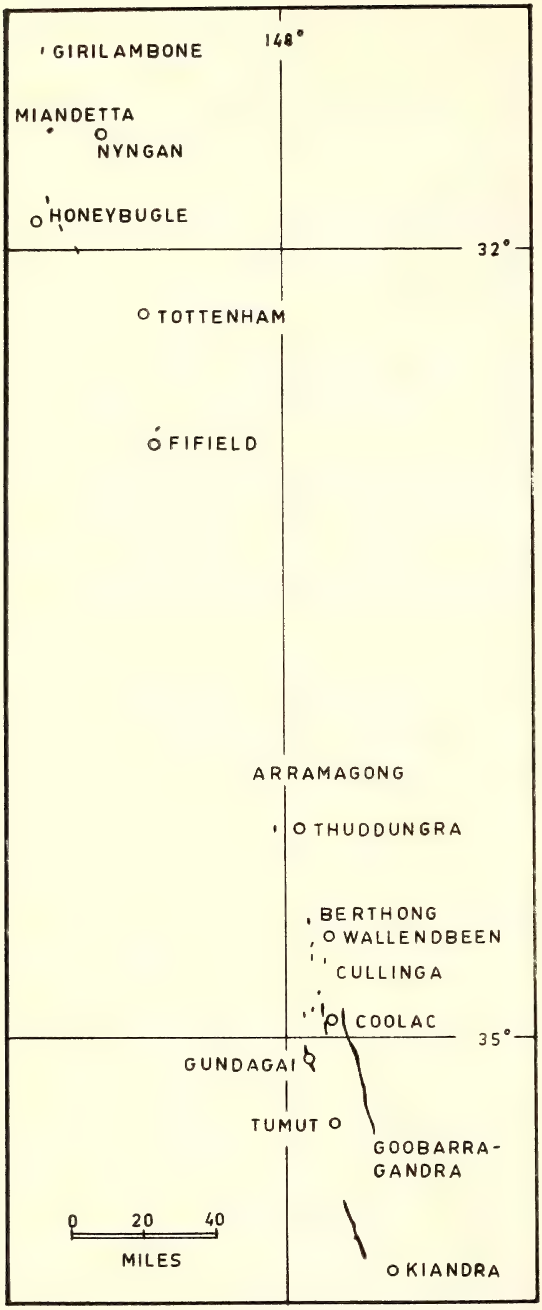

FIGURE 2.—Reported occurrences of ultramafic rocks in the Girilambone-Kiandra Belt.

more intensive study, and outlines a sequence of events to account for aspects of the observed rock association.

In the following account the terms Coolac belt or belt refer to the Coolac-Goobarragandra subsidiary unit, which is more closely defined hereunder.

2. Location and Physiography

The Coolac belt includes two steeply dipping, almost contiguous ultramafic lenses of unknown depth which are separated by a few hundred yards and which, end to end, outcrop almost continuously for 35 miles (56 km.) along the strike. The principal or northern lens is 27 miles long and attains a maximum thickness and outcropping width of about 2,200 yards (2 km.). The southern lens is composite and includes at least two narrow, sub-parallel serpentinite sheets separated by low-grade metamorphic rocks having a maximum overall width of about 600 yards.

The belt trends south-south-east from the Hume Highway, five miles north-east of Coolac and 240 miles by road west of Sydney; crosses the Murrumbidgee River at Gobarralong; passes some eight miles east of Tumut; and terminates one mile south of the Goobarragandra River, on Patten's Ridge (Figure 3). Outcrops of ultramafic rock beyond these limits (Golding, 1966; Boots, 1968) are not considered hereunder.

The region traversed by the belt is broadly divisible into three meridional physiographic zones which reflect lithologic and structural discontinuities. The eastern zone consists largely of a dissected plateau about 3,000 feet A.S.L. and is underlain by the Burrinjuck granite mass. The central physiographic zone is also a zone of major tectonism which encloses all the ultramafic rocks with the possible exception of certain wehrlites in the extreme north. This zone largely coincides with the ridges and scarps of the Mooney Mooney and Honeysuckle Ranges indicated, with subdivisions, in Figure 3.

The western zone descends to 800 feet A.S.L. at the Tumut River west of the ultramafic belt, and is underlain by Lower Palaeozoic, probably Silurian, sedimentary, volcanic and low-grade metamorphic rocks, folded about sub-meridional axes, locally intruded by porphyrites and, in the south, by the Bogong granite of probable Devonian age (Adamson, 1957; Veeraburus, 1963; Golding, 1966; Fraser, 1967; Boots, 1968).

3. Broad Lithologies and Structure

In the Honeysuckle Range both serpentinization and shearing increase westward so as to roughly demarcate an eastern sector predominantly of blocky, partly serpentinized hazrburgitic peridotite from a western sector of sheared serpentinite. This east-to-west division persists into the southern half of the Mooney

Mooney Range, but further north gabbroic rocks take the place of serpentinite on the west and are associated with wehrlite and harzburgite (Figure 4) in the North Mooney complex. The narrow southern lens is lithologically similar to the western sector of the Honeysuckle Range.

The ultramafic rocks are separated from the western beds by a marginal zone 10 to 100 yards wide of pseudo-concordancy, within which fault septa of serpentinite and western beds alternate. Cleavage in the western beds, lithologic-structural planes in the marginal zone, fractures in the serpentinite, major joints in the harzburgite and foliation in the eastern granite all trend with the strike of the belt and are subvertical. Faulted contacts of serpentinite with eastern granite and with western beds, along Bombowlee Creek Road and Tumorrama Road respectively, dip east at 65° to 80°.

The eastern flanking rocks consist partly of granodiorite and the terms granite and granitic are therefore used broadly hereunder. Granitic rocks are massive and leucocratic at North Mooney Ridge and Mt. Lightning, strongly foliated and biotite-rich along Mundongo Scarp, and variably foliated elsewhere. The intensity of the foliation decreases away from the contact. Granitic rocks of the same mass 10 and 20 miles east of the belt were respectively dated as Siluro-Devonian and Middle to Upper Devonian by Evernden and Richards (1962). Alkali olivine basalts, dolerites and limburgites of probable Tertiary age cap the granite at the eastern contact of the harzburgite on the Red Hill Plateau (Veeraburus, 1963). At Patten's Ridge a wedge of amphibole schists, epidosites and amphibolite separates the serpentinite from the eastern granite.

4. The Eastern Contact

The eastern contact is marked by a zone of brecciated granite up to several yards wide abutting peridotite in the Honeysuckle Range ; and by a selvage of laminated granite mylonite, some inches wide, abutting sheared serpentinite along Mundongo Scarp. Apophyses and thermal effects indicating liquid magmatic intrusion of either rock into the other ; schlieren of either rock within the other ; and fragments of ultramafic rock in the marginal granite breccia are all absent. Large enclosures of the eastern granite in marginal harzburgite, however, occur on both banks of the Murrumbidgee River and are either wedges stoped from the granite by ascending harzburgitic material, or locally infaulted slices. These features establish the overall tectonic character of the eastern contact but suggest that marginal granite brecciation pre-dated the existence of the harzburgite at the observed contact.

Although slices of peridotite, away from the contact, are flanked by selvages of sheared serpentinite between which they may have ascended tectonically, much peridotite and serpentinite at the contact itself is massive and lacks slickensides and megascopic brecciation. Thin sections, however, reveal post-serpentine microbrecciation which is superimposed on the normal pre-serpentine microcataclasis (Section 6). These features are compatible with the introduction of the harzburgite as a crystal mush into a pre-existing fracture and the subsequent ascent, minimal at the eastern contact but increasing westward, of slices of solid harzburgite.

Post-tectonic fluids localized by the fault promoted the formation of magnesite, chlorite, opal and chalcedony in marginal peridotite from place to place ; and induced sporadic metasomatism of the granite breccia to resistant prehnite- and zoisite-rich rocks which stand in relief along the contact.

5. The Western Marginal Zone

From north to south in the Mooney Mooney Range ultramafic rocks are successively flanked on the west by gabbros ; by intertonguing serpentinite and basic volcanics ; and by alternating septa of volcanics, rodingite, albitite, cherts and serpentinites. At Mt. Lightning some marginal basic volcanics enclose angular fragments of serpentinite ; others consist of unaltered spilitic variolite (Golding, 1966). Shales abut serpentinite in the Adjungbilly Valley and separate prominent sheets of sheared serpentinite along the Tumorroma Road. Andesitic rocks intertongue with serpentinite along Keef's Scarp and persist to the southern extremity of the belt.

The development of the western marginal zone presumably involved (i) the ascent of harzburgitic mush into wet sediments and volcanics ; (ii) the concomitant coherence and serpentinization of the mush ; and (iii) the piecemeal ascent of serpentinite, and perhaps of lenticles of country rock, by slip on fracture planes. The recurrence of such movements is possible, perhaps when compression coincided either with hydrothermal episodes or with heating and dehydration of serpentinite (Raleigh, 1967).

The tectonic zone has been regarded as an overthrust (Browne, 1929) and as a possible strike-slip fault (Lambert and White, 1955 ;

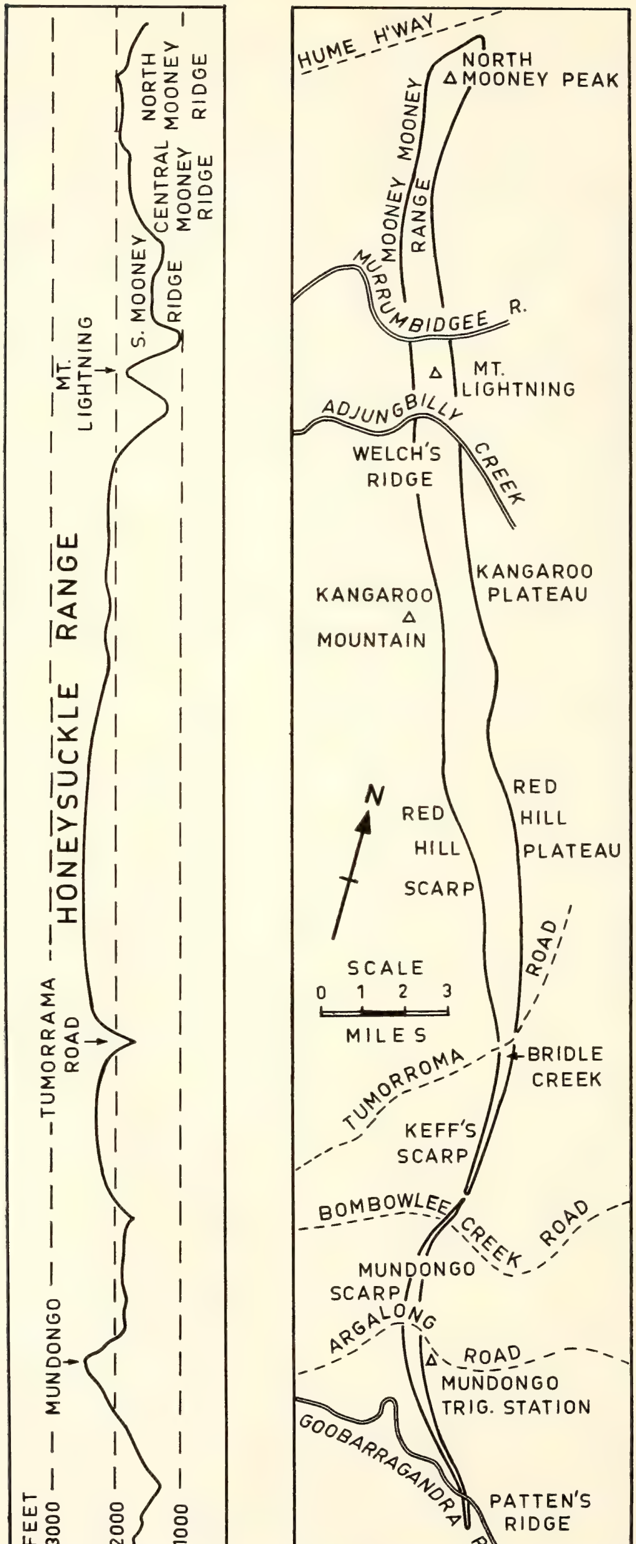

FIGURE 3.—The Coolac-Goobarragandra ultramafic belt—physiographic features. Meridional section (left) and plan (right).

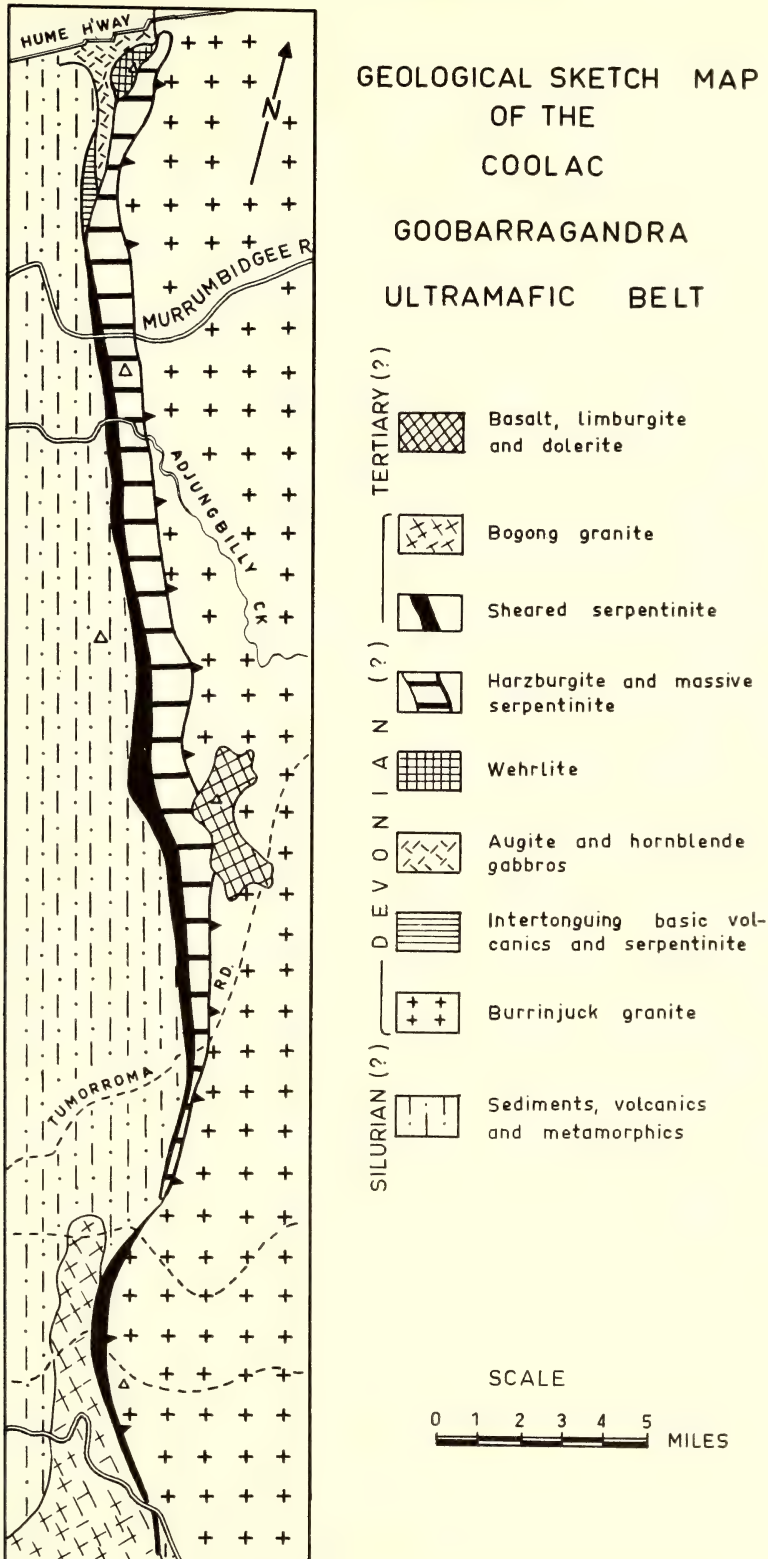
HUME H'WAY
N
MURRUMBIDGEE R
ADJUNGBILLY CK
RD.
TUMORROMA
GEOLOGICAL SKETCH MAP
OF THE
COOLAC
GOOBARRAGANDRA
ULTRAMAFIC BELT
TERTIARY (?)
Basalt, limburgite and dolerite
DEVONIAN (?)
Bogong granite
Sheared serpentinite
Harzburgite and massive serpentinite
Wehrlite
Augite and hornblende gabbros
Intertonguing basic volcanics and serpentinite
Burrinjuck granite
SILURIAN (?)
Sediments, volcanics and metamorphics
SCALE
0 1 2 3 4 5
MILES

FIGURE 4.

Rod, 1966). Because it may delineate a major relict lateral crustal discontinuity, and a fracture which extended to the mantle (Ringwood, 1964), its evolution is regarded as the principal geologic problem of the belt. The contents of the zone present a more or less independent series of problems.

6. The Honeysuckle Range Harzburgite

In terms of reconstructed (anhydrous) minerals, the harzburgite contains 60–95% (usually $\simeq$80%) of olivine, 2–40% (usually $\simeq$15%) of enstatite, up to 5% (usually $\simeq$1%) of diopside, and about 1% of chromite. Commonly, about half the olivine and enstatite are serpentinized ; local transitions of harzburgite to bastite serpentinite are frequent ; and occasional lenses of dunitic serpentinite devoid of pyroxene and bastite occur around chromite deposits and elsewhere in the eastern sector. In most outcrops the rock is massive, but a few reveal alternating enstatite-rich and dunitic layers, 1–2 cm. thick, traceable over a few feet.

Megascopically, the harzburgite and derived serpentinite show orthopyroxenes, 5 mm. wide, within a groundmass which varies from medium grey and finely granular in rocks with densities of 3·0 g. cm.^{3}, which contain up to 6% of combined water ; to black and aphanitic in rocks with densities of 2·7–2·4 g. cm.^{3} which contain 9–11% of combined water (Table 1).

Thin sections of harzburgite reveal rare clusters of olivine grains with allotriomorphic granular fabric and grains up to 2 mm. wide showing deformation lamellae. Usually disoriented olivine sub-grains, 0·1 mm. wide, are cemented and replaced by unfractured bluish-grey serpentine enclosing sporadic magnetite granules. The olivine, about $Fa_7(2V_z=86\pm3°)$ was fragmented before or during serpentinization.

The enstatite near En_{90} $(2V_z=84\pm3°)$ encloses lamellae of clinopyroxene, and is ragged, warped and marginally replaced by recrystallized (?) olivine. The diopside and chromite grains are angular.

The pervasive cataclasis of the harzburgite might be attributed to slumping or compressive deformation of a cumulate derived from mafic magma more or less at the observed site (Challis, 1965 ; Challis and Lauder, 1966). Other features of the Coolac rocks (Section 9), however, favour the ascent of the harzburgite in a largely crystalline condition from a substantially deeper level.

Apart from possible upthrusting of masses or slices of solid rock ; proposed mechanisms for the emplacement of alpine-type peridotite which emphasize the role of solid components range from (1) emplacement of a crystallo-magmatic suspension (Smolin, 1964) ; and (2) of a stiff, semi-solid crystal mush rendered mobile by crushing, local melting and recrystallization, and capable (at times) of magmatic flow (Thayer, 1963*a*, 1964) ; to (3) emplacement of a near-solid crystal mush deforming plastically during the removal by filter-pressing of associated liquid (Raleigh, 1965) ; and (4) emplacement of a completely crystalline mass deforming at low to moderate temperatures by recrystallization and crushing (Ragan, 1963, 1967) ; or (5) deforming at higher temperatures by recrystallization alone (Green, 1964, 1967).

The Honeysuckle Range harzburgite was probably emplaced in a heterogeneous manner involving several of these mechanisms which changed with increasing coherence of the mush during the emplacement period.

The harzburgite presumably originated either as a gravity differentiate of a mafic magma or as a refractory residue formed by the partial fusion of pyrolite (Ringwood, 1964 ; Ringwood and Green, 1966) and the incomplete segregation of the fused and residual fractions. By either origin the material would have been largely crystalline, but associated with subordinate liquid, at its inception. The re-emplacement of this crystal mush within the tectonic zone during appropriate stresses to high crustal levels is visualized. Further aspects of the re-emplacement are suggested by the enclosures of other rocks within the harzburgite (Section 9).

7. The North Mooney Complex

This complex occupies two to three square miles, mainly west of North Mooney Ridge, and is characterized by wehrlitic, gabbroic and harzburgitic rock types the mutual relations of which are obscure. The third type is probably an extension of the Honeysuckle Range harzburgite, but apart from some inclusions within serpentinite (Section 10) more than 20 miles to the south the other types appear to be absent elsewhere in the belt.

(*a*) *The Wehrlites*

These rocks contain from 50% to more than 90% (and $\simeq$80%) of diopside and thus grade into clinopyroxenite. Orthopyroxene and feldspar are absent. Olivine, the second constituent, is usually represented by felted antigorite. Fine-grained (1 mm.) and coarser

(5–10 mm.) and massive and foliated types occur. The rocks are tougher than the harzburgite. Fractured surfaces of pyroxene-rich types are greyish-green.

Some wehrlite outcrops are separated by antigorite serpentinite presumably derived from dunite. This relation may represent (i) dykes of wehrlite in dunite or *vice versa*, (ii) associated tectonic slices of the two rocks, or (iii) wehrlite-dunite layering of settled, magmatic flowage or metamorphic types. Settled layering, however, is suggested by changes in the pyroxene-olivine ratio and in the grain-size of the pyroxene, in different specimens from the area; and by the microtextures.

Thin sections reveal colourless twinned diopside near $Ca_{41}Mg_{57}Fe_2$ ($2V_z=55°$, $N\beta=1\cdot672$), occasionally with marginal secondary amphibole. The crystals are variably fractured, but never granulated, and mush re-emplacement involving crushing is ruled out. The texture varies with the pyroxene-olivine ratio. Pyroxene-rich wehrlite reveals either allotriomorphic granular diopside with small interspaces containing antigorite, or shows frameworks of subhedral grains making point contacts. In pyroxene-poor wehrlite single diopside grains and small grain clusters appear to float in antigorite.

Two varieties of basic pegmatite occur within the wehrlite. These are firstly segregations a few feet thick of green clinopyroxene several centimetres wide, separated by cream-coloured saccharoidal zoisite, and secondly smaller patches of coarse hornblende associated with white saussurite which are localized along fissures near the junction with gabbros (Subsection (*c*) below).

(*b*) *Marginal and Local Peridotite Variants*

Near the contact with granite in the extreme north the wehrlite contains a little garnet and turbid material, and occasionally veinlets of garnet, chlorite and serpentine replace olivine and diopside. Elsewhere in the mass rocks containing more antigorite than diopside, enstatite and antigorite, and enstatite and turbid material occur. Near the junction of wehrlite and harzburgite occasional veins of clinopyroxenite 1–2 cm. wide penetrate harzburgite. Rocks with distinctive magmatic textures also occur. In one variant green spinel separates clinopyroxene crystals enclosing resorbed olivine grains. In another, resorbed olivine is enclosed within ortho- and clinopyroxene, which abut pale brown amphibole.

(*c*) *Gabbroic Rocks*

Of these rocks some contain variably uralitized augite, others additionally contain a brown-green hornblende, and a third group contains hornblende to the exclusion of augite and uralite. Other constituents include saussuritized plagioclase, chlorite, leucoxenized opaques, zoisite veinlets and, rarely, traces of garnet. The hornblende gabbros predominate in the north of the gabbro area (Figure 4), and possibly separate the wehrlite from the augite gabbros. Most outcrops of gabbroic rocks reveal uneven and coarse-grained apophyses intruding country rock volcanics. Such gabbros apparently crystallized in place from volatile magma, and some apophyses may represent country rocks remobilized by volatiles. In places hornblende gabbro (or diorite) intrudes volcanics which contain angular blocks and fragments of (?) similar gabbro (or diorite).

The status of the North Mooney complex is problematic. Gabbro-wehrlite associations elsewhere occur in belts of serpentinized harzburgite (Taliaferro, 1943; Rynearson and Wells, 1944), in some stratiform and pseudostratiform complexes (Irvine and Smith, 1967; Rothstein, 1957; Smith, 1958), and in the Ural-Alaskan type of zoned complex (Ruckmick and Noble, 1959; Taylor and Noble, 1960; Taylor, 1967).

Whether the wehrlite and gabbro are normal associates of the Honeysuckle Range harzburgite which have been largely removed by erosion, or whether the complex is fundamentally of a localized type, remains to be determined.

8. The Serpentinites

X-ray and differential thermal analysis using the respective criteria of Whittaker and Zussman (1956) and Faust and Fahey (1962) indicate that the bastite serpentinites of the Honeysuckle Range consist predominantly of associated lizardite and chrysotile. Increasing westward serpentinization of this type within the harzburgite is compatible with an influx of water into the peridotitic material from the western beds (Section 5). An increase in ferric at the expense of ferrous iron, and a decrease of lime accompanying increasing hydration of these rocks seems likely (Table 1). The bastite serpentinites are green or black, and the dunite serpentinites often brown or grey with purple haematitic streaks, suggesting the field term serpentine pseudobreccia. Thin sections reveal a mesh texture in most of these rocks, with brown turbid patches in the pseudobreccias. Sulphide and awaruite particles are conspicuous in some types (Golding, 1963, 1966).

Antigorite serpentinite predominates on North Mooney Ridge, and is accompanied by antigorite-talc and talc-magnesite rocks on Central Mooney Ridge. These rocks derived from dunite, harzburgite and pre-existing bastite serpentinite, the final modifications of which may have been promoted by one or other of the gabbroic intrusions or late magmatic fluids associated with them. In the Bombowlee Creek-Mundongo area antigorite serpentinites are associated with chlorite-, talc-, magnesite- and amphibole-bearing serpentinites (Fraser, 1967), the formation of which was influenced, at least partly, by the intrusion of the Bogong granite.

TABLE 1

Chemical Analyses of Serpentinized Harzburgites and Serpentinites[1]

	1	2	3	4	5	6
SiO_2 ..	41.79	40.88	40.24	39.82	39.92	39.71
Al_2O_3 ..	2.28	1.30	1.96	1.12	0.04	0.34
Fe_2O_3 ..	1.40	2.18	4.80	5.27	7.53	8.51
FeO ..	6.25	5.77	3.35	2.80	2.15	0.84
MgO ..	39.52	41.49	36.88	38.78	38.52	36.67
CaO ..	2.35	1.51	2.29	0.54	0.18	Nil
Na_2O ..	0.05	0.10	—	0.04	0.03	0.01
K_2O ..	0.04	0.06	—	0.02	0.02	tr.
H_2O+	5.45	5.66	8.75	10.72	10.84	11.15
H_2O-	0.03	0.32	0.23	0.08	0.04	1.90
CO_2 ..	0.09	Nil	0.11	0.22	0.32	Nil
TiO_2 ..	0.05	0.02	—	0.03	0.03	0.02
P_2O_5 ..	tr.	tr.	0.02	0.03	0.02	tr.
F ..	—	—	Nil	0.13	0.14	—
Cr_2O_3 ..	0.38	0.35	0.45	—	—	0.55
MnO ..	0.11	0.15	0.92	0.11	0.06	0.06
NiO ..	0.17	0.25	0.22	—	—	0.46
Li_2O ..	—	—	Nil	0.01	0.01	—
Free C	0.10	Nil	Nil	0.07	0.12	Nil
Totals*	100.06	100.04	100.22	99.73	99.91	100.22
S.G. ..	3.03	3.00	2.67	2.45	2.54	2.34

* Corrected for loss $0=F_2=0.06$ in analyses 4 and 5.

[1] Arranged in order of increasing water content from left to right. Samples 1–4 from the eastern, and samples 5 and 6 from the western sector.

Sample 1 : Grey, fine-grained, partly serpentinized harzburgite. Mt. Lightning.

Sample 2 : Grey fine-grained, partly serpentinized harzburgite. Mt. Lightning.

Sample 3 : Grey to black, fine-grained to aphanitic, massive bastite serpentinite containing about 25% of unaltered olivine and pyroxene. Adjungbilly Valley.

Sample 4 : Black, aphanitic, massive bastite serpentinite containing small amounts of unaltered olivine and pyroxene. Tumorroma Road.

Sample 5 : Sheared serpentinite containing traces of unaltered olivine and pyroxenes. Tumorroma Road.

Sample 6 : Massive, grey serpentine pseudobreccia with purple streaks, completely serpentinized and somewhat porous. Adjungbilly Creek.

Analysts : Samples 1, 2 and 6 : J. H. Pyle (N.S.W. Mines Dept.) ; Sample 3 : R. Fisher (Sydney) ; Samples 4 and 5 : A. Ithikasem (Thai Geol. Survey).

Sources : Samples 1, 2 and 6 : Golding (1966) ; Samples 3, 4 and 5 : Veeraburus (1963).

Lizardite-rich pods of black serpentine up to a few centimetres wide, separated by slickensided platy chrysotile, predominate within the sheared serpentinites of the western sector. Additional local variants of serpentinite have been described by Golding (1966) and by Golding and Bayliss (1968*b*).

9. Enclosures in the Harzburgite

Enclosures account for about five volume per cent. of the harzburgite. These are (*a*) the garnet-vesuvianite (Group 1) rodingites, and the " sub-rodingites ", (*b*) the Haystack Creek metasomites (including the Group 2 rodingites), (*c*) the acid feldspathic rocks, and (*d*) the chromitite pods. Groups (*a*) and (*c*) (above) account for about 60% and 30% of the enclosures respectively. The apparent structural relations of the enclosures to the harzburgite are indicated in Table 2.

(*a*) *The Garnet-Vesuvianite Rodingites*

These rodingites are pale coloured rocks with a " flinty " or finely sucrose to coarsely gabbroic megascopic appearance. They contain variable amounts of garnet ($N=1{\cdot}700$–$1{\cdot}735$) belonging to the grossular-hydrogrossular series, vesuvianite, chlorite and relict non-cataclastic diopside, all of which are colourless in thin section. Amphiboles and serpentine minerals are rare accessories. The occurrence of garnet in wehrlite and gabbro (Section 7) is excluded from consideration here.

These rocks form tabular bodies up to 50 ft. long and 3 ft. wide, but usually much smaller, which occupy sub-vertical, usually meridional spaces in massive harzburgite and serpentinite. They are most abundant along North and Central Mooney Ridges and at Mt. Lightning. Some masses are homogeneous, but streaky and patchy mineral segregations occur in others. Marginal slickensides and brecciation are absent or rare. The rocks are similar to those elsewhere regarded as metasomatized basic dykes (Arshinov and Merenkov, 1930 ; Miles, 1950 ; Bloxham, 1954 ; Baker, 1958), but dissimilar to the rodingitized tectonic inclusions within sheared serpentinite (Schlocker, 1960 ; Vuagnat, 1965 ; Coleman, 1966).

FIG. 1.—Chromite-rodingite breccia from the Vulcan South Mine, North Mooney Ridge.

FIG. 2.—Rodingite veins (white) transecting and offsetting schlieren-banded (spotted and streaky) chromitite (chromite with serpentine minerals) and massive chrome ore (black) from the Mooney Trig Mine, North Mooney Ridge.

Although lime released during serpentinization possibly contributed to metasomatism, the presence of unaltered diopside in some wall rocks, and the availability of lime in the precursor rocks and magmas themselves, suggest the latter as the major sources of the added lime in the Group 1 rodingites.

Many Group 1 rodingite bodies appear to be rootless dykes which represent pockets of residual gabbroic magma, and some, at least, either consolidated and were metasomatized at the observed sites or have been transplanted, together with their wall rocks in larger, fault-bounded, composite blocks from pre-existing sites.

The occurrence of a rodingite vein sharply transecting and offsetting magmatic flow layers (Sub-section 9 (*d*)) in chromitite (Plate 1, Fig. 2) and the previously noted inter-relationships jointly indicate that chromitite was the earliest and the rodingite precursor the latest rock to consolidate.

While a two-stage origin involving precipitation of gabbroic minerals, followed by rodingitization, is visualized for many Group 1 rodingites, some may be direct precipitates from a more aqueous fluid (Anirudda, 1967), and narrow veinlets of monomineralic chlorite, garnet and vesuvianite in some of the chromitites may be related to such a fluid. The variable hydration of the precursor fluid is also suggested by tabular bodies of brown hornblende-prehnite rock and by others containing fibrous (? tremolitic or lamellae-bearing) clinopyroxene and zoisite. These bodies, here termed "sub-rodingites", were encountered only at Bridle Creek and Mt. Lightning, but may have been overlooked elsewhere since their grey colour differs only slightly from that of the harzburgite host.

TABLE 2

Enclosure Types Within the Harzburgite

Structural exotics (mechanically transported)	Exogenous	Infaulted wedges of eastern granite (*c*),* Murrumbidgee and Red Hill. ? Fault-displaced segments of marginal granite micro-breccia (*c*), Keef's Scarp.
Mush-transported exotics, autoliths, and roof pendants	Exogenous (xenoliths)	Composite feldspathic body (*c*), Tumorroma Road.
	Endogenous (autoliths)	Chromitites (*d*). ? Wehrlite roof pendants east of Mooney Peak.
Liquid magmatic intrusions and rootless dykes essentially at the site of consolidation	Exogenous	Non-cataclastic granite-aplite dykes (*c*), Patten's Ridge. ?Variolite apophyses and derived metasomites (*b*) at Mt. Lightning.
	Endogenous (co-magmatic)	Garnet-vesuvianite-chlorite rodingites (*a*). "Sub-rodingites" (*a*). ? Wehrlite dykes and apophyses east of Mooney Peak. Cataclastic acid feldspathic enclosures (*c*).

* (*a*)–(*d*) as in introduction to Section 9.

Group 1 rodingite dykes and veins frequently transect chromite deposits, particularly in the north of the belt. The intrusive *in-situ* character of the precursor magma with respect to the chromite host is unambiguous, and rodingite-chromite breccia (Plate 1, Fig. 1) indicates that the chromite was competent when the precursor magma was injected.

The rarity of dykes of harzburgite (or serpentinite) in chromitite, and the absence of harzburgite-chromite breccia and of rodingite-harzburgite breccia contrast with the rodingite-chromite associations. These relations reflect marked differences between the physical states of the harzburgite and rodingite precursor materials and between the competency of the chromitite and harzburgite hosts of rodingite.

Although Group 1 rodingites are abundant near the augite gabbro in the Mooney Mooney Range, they are also abundant at Mt. Lightning, where gabbro is lacking. The rodingites and augite gabbros may have derived from the same initial source (inter-cumulus liquid or partial melt), but if so their history diverged. The

uralitization and ensuing saussuritization (see Ehlers, 1953 ; Harpum, 1954) of the augite gabbro did not result in Group 1 rodingite minerals except on a microscopic scale. Conversely, Group 1 rodingites contain little or no amphibole or zoisite. The alteration of basic rocks in the Coolac belt thus followed three trends : the uralitic-saussuritic, the Group 1 rodingitic, and the Group 2 rodingitic (sub-section 9 (*b*)). When the mush liquid did not precipitate as gabbroic Group 1 precursor material, it may have split into pyroxenitic or amphibole-rich (" sub-rodingitic ") and feldspathic (Sub-section 9 (*c*)) fractions. The consolidation of the Group 1 rodingitic precursor, " sub-rodingitic " and feldspathic bodies was probably the final event in the bulk coherence of the harzburgitic mass.

(*b*) *The Haystack Creek Metasomites*

Although prehnite- and zoisite-bearing rocks appear in diverse settings (Section 4 ; Section 7, Sub-section (*a*)) in the belt, the occurrences at Haystack Creek, Mt. Lightning, are the most distinctive. Haystack Creek (Golding, 1966) marks the eastern junction of a mass of variolite about 300 yd. long and 50 yd. wide within the eastern sector. The least altered variolite is megascopically similar to that in the western marginal zone (Section 5), 700 yd. distant, but thin sections show it to be prehnitized.

One group of rocks in the creek includes a series of greenish-grey metasomites derived from basic rocks of doubtful status, in which colourless amphibole is the sole constituent in some outcrops but is associated with antigorite ; with prehnite ; and with diopside, chlorite, prehnite, clinozoisite and sphene in adjacent outcrops.

Another group of rocks includes pale coloured, fine-grained metasomites which vary from homogeneous to gneissic in structure, and include several with relict variolitic texture. Most of these rocks formed at junctions of peridotite or serpentinite either with variolite or with acid feldspathic rocks. Some outcrops reveal up to six metasomatic zonal segregations with vertical junctions. These rocks (the Group 2 rodingites) contain variable amounts of prehnite, zoisite, garnet, chlorite and sphene. They differ from the Group 1 rodingites as follows : diopside and vesuvianite are absent, calcite is present in some, the chlorite is greenish, and prehnite and zoisite are characteristic and occur in substantially monomineralic rocks. The garnet, however, is similar.

The metasomatism at Haystack Creek is of the lateral or contact type and may have been promoted by the water which induced serpentinization in the associated rocks, or by fluids of other affiliations.

(*c*) *The Acid Feldspathic Rocks*

These are streaky grey and white, cherty and fine-grained rocks occurring in small masses similar in size and shape to that of the Group 1 rodingites. They are strongly micro-cataclastic and exhibit micro-faulted and impacted feldspars with bent twin lamellae, intensely sutured quartz and abundant mylonite. Single samples are not representative of a given mass.

Specimens from Keef's Scarp contain microperthite, oligoclase, quartz, leached biotite, rosettes of pale amphibole and zoisite. Plagioclasite with zoned andesine to oligoclase, muscovite, chlorite, sphene, quartz and zoisite ; and albitite with striated and checker-board albite, chlorite, sphene, leucoxene and (?) stilpnomelane occur in different masses along Haystack Creek. From a single mass on Red Hill plateau each of eight specimens revealed different assemblages : microcline-, plagioclase-, albite-, chlorite- and carbonate-rich, as well as hornblende-, garnet- and pyroxene-bearing types being represented.

Similar enclosures in ultramafic rocks elsewhere have been regarded as foreign intrusions (Benson, 1913 ; Watson, 1953) or hydrothermal bodies (Francis, 1955), as co-magmatic differentiates of the ultrabasic magma (Arshinov and Merenkov, 1930 ; Suzuki, 1953), as co-magmatic and metasomatic members of the " alpine mafic magma stem " (Thayer, 1963*b*, 1967), as metasomatic complements of rodingite (Green, 1958), as metasomatized gabbro (Olsen, 1961), as reconstituted sediments (Baker, 1958), and as metasomatized sediments and volcanic rocks (Coleman, 1966 ; Leonardos and Fyfe, 1967).

Diorites containing zoned plagioclase may be differentiates of the gabbroic precursor magma of Group 1 rodingite. Some other types appear to be metasomatic modifications of this diorite or of gabbro. The reciprocal rodingitization of gabbro at one point and its acid feldspathization at another seems possible. The cataclasis suggests movement of largely crystalline material during emplacement and metasomatism.

Some enclosures may represent fault-displaced segments of marginal granite micro-breccia ; and a composite feldspathic body within harzburgite along the Tumorroma Road is

probably a xenolith derived from the Burrinjuck granite. Aplite dykes associated with the Bogong granite contain micrographic intergrowths of quartz and microperthite and are non-cataclastic.

(*d*) *The Chromite Segregations*

Lenses (pods) of massive and disseminated chromite (chromite deposits, chrome ores, chromitites) up to 200 ft. long and a few feet wide, but usually much smaller, are unevenly distributed within the harzburgite, and over a length of 5 km. along Welch's Ridge they appear to be absent. Textures indicate their development in three principal stages : (i) an abyssal or cumulate stage, (ii) a re-emplacement, desegregation or deformational stage when flow-layering and lineation were superimposed on cumulate textures (Golding, 1966, 1967*b*), and (iii) a stage of metasomatic modification (Golding and Bayliss, 1968*a*).

The principal silicates in the ores are olivine, diopside, serpentine minerals and chlorites. These form the matrix of chromite fragments in flow-layered ore, but fill intercumulus spaces, or occupy fractures and breccia spaces in massive ore. The distinction of primary silicates and their derivatives from subsequently introduced rodingitic and other material, and from material fortuitously intermixed with, or juxtaposed against, chromite during re-emplacement and tectonism, is thus dependent on the recognition of primary textures which are preserved in small relict portions of ore.

The sizes of the chromite and olivine grains in undeformed Coolac ores are significantly larger than those in the stratiform (Bushveld and Stillwater) chromitites (Jackson, 1961, 1963) and point to differences in the duration, depth or other conditions of crystallization.

Characteristic compositional features of the primary (unaltered) chromite are (i) the low content (usually $<5\%$) of Fe_2O_3, and (ii) the large variation in Cr_2O_3 and Al_2O_3 (Table 3). Chemical analyses of chromite concentrates from 29 deposits and further data based on a linear relation between the $Cr_2O_3 : Al_2O_3$ ratio and the cell dimensions (Golding, 1966) indicate that Cr_2O_3 varies from 62 to 34 and Al_2O_3 from 6 to 34 weight per cents. There is also a bimodal frequency distribution of the deposits with respect to the $Cr_2O_3 : Al_2O_3$ ratio, with major and secondary maxima at about 57% and 37% Cr_2O_3 (and 10% and 30% Al_2O_3) respectively. Of the seven largest deposits, five contain Cr-rich and two contain Al-rich chromite.

The Cr-rich chromite is usually associated with mesh texture serpentine derived from olivine in deposits throughout the belt. At Mt. Lightning and at North and Central Mooney Ridges and near the Tumorroma Road, however, these deposits are interspersed with others containing Al-rich chromite associated with diopside or with derived chlorite containing minute garnets. The Cr-rich chromite accumulated, and probably precipitated with olivine, and the Al-rich chromite apparently accumulated and may have precipitated with diopside. The greater frequency of resorbed chromite in the Cr-rich, but of relict primary textures in the Al-rich, chromite suggests that the former had a longer history.

TABLE 3

Chemical Analyses of Cleaned Chromite from Segregations in the Honeysuckle Range Harzburgite

	1	2	3	4
Cr_2O_3	31.3	35.8	59.1	59.9
Al_2O_3 ..	33.6	30.1	10.0	5.8
Fe_2O_3 ..	4.9	2.2	4.9	17.1
FeO	8.2	11.2	12.8	
MgO	17.4	17.1	12.4	14.5
MnO	0.2	0.1	0.2	0.2
TiO_2 ..	0.1	0.1	0.1	0.2
SiO_2	0.7	1.8	0.3	1.0
H_2O	1.0	—	0.1	1.4
Etc.	0.2	0.1	0.2	—
Total ..	97.6	98.5	100.1	100.1
a_0 Å ± 0.005 ..	8.213	8.217	8.312	8.317

1. Chromite with a little chlorite impurity. Vulcan North Mine. North Mooney Ridge.
2. Chromite with chlorite and traces of relict diopside. Quilter's South Mine, Mt. Lightning.
3. Chromite with a little serpentine impurity. Mt. Miller Mine, Tumorroma Road.
4. Chromite with a small amount of chlorite, serpentine, grossularite and opal. Kangaroo East Mine, Honeysuckle Range.

Analysts : Nos. 1 and 3 : Mines Dept., N.S.W. ; Nos. 2 and 4 : B.H.P. Co. Ltd., Newcastle, with a separate determination of FeO (analysis 2) by R. Fisher, Sydney.

The two chemically and mineralogically contrasting ore types presumably derived penecontemporaneously from contrasting magmas or magma domains, or at different periods from different magmas or from a magma the chemical and/or physical character of which changed with time. The close proximity at several localities and within identical harzburgite of the two chromitite types suggests that at least one type originated in a different environment from that in which the harzburgitic minerals

precipitated, if such minerals are in fact magmatic precipitates (and not refractory residues). It is concluded that some chromite pods at least have a " primary exotic " relation to their containing rocks.

The ore pods may represent fragments of former layers, but their stream-lined shapes (Golding, 1966) and scattered distribution suggest that after isolation the pods were entrained within and re-emplaced with the harzburgitic mush, as proposed by Thayer (1960, 1964), for podiform chromite deposits generally. To some extent, therefore, all the pods have a " secondary exotic " (autolithic or xenolithic) relation to their present host rocks.

The occurrence elsewhere of Cr-rich chromite deposits in feldspar-free peridotite masses and of Al-rich chromite deposits in ultramafic complexes containing feldspathic members was noted by Thayer (1946). The Cr-rich Coolac chromites are similar to those of the Pacific Coast Province (Thayer, 1946). The Al-rich Coolac chromites are similar to those in East Oregon (Thayer, 1946), in Camaguey, Cuba (Flint *et al.*, 1948), in the Philippines (Stoll, 1958) and in the Kempirsay pluton in the south of the Uralian geosyncline (Pavlov and Chuprynina, 1967), all of which are associated with gabbro, troctolite or anorthosite and several of which contain anorthite in the chrome ores. The absence of feldspar or its alteration products in the Al-rich Coolac ores may indicate their formation at greater pressures than those which operated elsewhere (Turner and Verhoogen, 1960, pp. 130–31 ; Kushiro and Yoder, 1964 ; Irvine, 1967).

If the usual sequence from lower peridotitic to higher feldspathic members in stratiform and pseudostratiform peridotite-gabbro complexes is applicable to the precursor complex of the Coolac rock association, Cr-rich chromitites originated at lower levels, and the Al-rich chromitites at higher levels (nearer the feldspathic material). The regional distribution of the Coolac chromitites also points to a relation between the Al-rich type and the more calcic and aluminous members (rodingites, gabbros and wehrlites) of the Coolac rock association.

10. Enclosures in the Serpentinite

These enclosures increase westward and include (i) fragmented representatives of the types which occur in the harzburgite, tectonic inclusions of country rock (Section 5) and their metasomatic derivatives, (ii) sulphide deposits, (iii) isolated masses of quartzo-feldspathic and cordierite - spinel - anthophyllite hornfelses (Golding, 1966), and (iv) certain metagabbroic and wehrlitic enclosures referred to below.

A mass of heterogeneous metagabbro about 300 ft. long and 50 ft. wide lies within schistose serpentinite of the western sector along the Tumorroma Road. Some portions are pyroxene- and other portions amphibole-bearing ; fabrics are partly granoblastic and partly igneous and metasomatic (Golding, 1966). Another metagabbro enclosure and also one of wehrlite similar to that in the North Mooney complex occur within serpentinite two miles to the north of the Tumorroma Road (Veeraburus, 1963). These occurrences suggest the former existence in this area of intrusions similar to those in the north of the belt. The serpentinite has moved around these enclosures, the earlier history of which is problematic.

11. Speculations on the Genesis of the Ultramafic Association

Assuming the origin of the harzburgite either as a cumulate or as a refractory residue (Section 6), a stage existed when harzburgitic mush formed the lower component and liquid mafic magma the upper component of a bipartite, abyssal mush and magma complex. Its depth of formation (Green, Green and Ringwood, 1967), duration at one or successive depths, and the independent history of the components would have influenced the derived rock association.

With a protracted duration, the formation of transitional cumulate mushes of dunitic, wehrlitic or troctolitic character might be envisaged and may be exemplified at the Bay of Islands, Newfoundland (Smith, 1958). If the harzburgite is a cumulate, Cr-rich chromite may have accumulated with it and Al-rich chromite may have accumulated with higher level transitional mushes. If the harzburgite is a refractory residue, and provided no chromite segregations derived as such from pyrolite, Cr-rich chromite may have accumulated at the interface of harzburgitic and transitional mushes, and Al-rich chromite at the higher level interface of transitional mush and magma.

The subsequent history of an abyssal complex of the second type intersected by the tectonic zone, or its precursor, might be visualized, in outline, as follows : The mafic magma advanced ahead of the transitional mush and the latter, remobilized on ascending to lower pressure levels, in turn preceded the more sluggish harzburgitic mush. Disrupted Cr-rich chromite

segregations, released from the lower interface, were captured by and entrained within but tended to lag behind, the frontal edge of the harzburgitic mush. Al-rich chromite masses released from the higher interface entered the mush later. A second-order vertical zonation of chromite autoliths thus developed within the rising front of the mush. A near-frontal mush zone enclosing Al-rich and the smaller and less compacted Cr-rich autoliths preceded a zone enclosing the larger and denser Cr-rich autoliths which, in turn, preceded barren harzburgitic mush.

Of the earlier expressed mafic and transitional magmas, a portion reached the surface through sporadic volcanic feeders and other portions consolidated in sub-volcanic reservoirs. Accompanying further tectonism, the harzburgitic material continued its ascent and pierced the roots of the earlier intrusions and down-folded portions of the earliest extrusions.

Assuming mush re-emplacement doming, or block or slice tectonic uplift of the central part of the belt (between the Adjungbilly Valley and the Tumorroma Road), erosion could account for the observed rock and ore distribution. Thus, near-frontal harzburgite enclosing mixed chromite autoliths, abundant Group 1 rodingites and related enclosures (near the roof of the harzburgite), together with volcanics, gabbro and wehrlite representing the earlier mobilized magmas, are exposed in the north; but elsewhere have been eroded so as to uncover deeper levels of harzburgite enclosing Cr-rich chromite autoliths, and, in the centre of the dome (Welch's Ridge-Kangaroo Plateau), the still deeper zone of barren harzburgite.

The peridotite-gabbro association of the Coolac belt, according to this interpretation, is a mush- and partly tectonically-re-emplaced and also partly re-intruded abyssal complex in which a quasi-stratiform configuration of mush and magma components at depth was to some extent reproduced but also telescoped at shallower levels.

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Radio-Carbon Datings of Ancestral River Sediments on the Riverine Plain of South-eastern Australia and Their Interpretation

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ABSTRACT—This paper deals with the configuration of Quaternary sediments of the Riverine Plain. The origin of fluviatile sediments and their relationship to the present river system is discussed. It is shown that the Older Alluvium of the Plain is relatable to a series of prior streams which are still traceable as a relict distributory stream system. The Younger Alluvium is deposited by ancestral rivers which form a tributary pattern. The ancestral river system displays evidence of three separate phases of stream activity. Radio-carbon datings of wood samples from sediments representative of the three phases are presented. Results substantiate the earlier published relative chronology. A palaeo-climatic interpretation of the presented carbon dates, and those published previously, is put forward.

The purpose of this paper is to present new datings of three reliable carbon samples obtained from ancestral river sediments and to correlate these with earlier published dates. With relatively few dates available at this stage, inferences drawn from the limited data should still be regarded as contributions towards an eventual understanding of the region's geochronology.

Surface sediments of the Riverine Plain consist of two geological subdivisions: the Older and Younger Alluvium. Sediments deposited by prior streams (Butler, 1950) are the Older Alluvium, while Younger Alluvium consists of the ancestral river (Coonambidgal) sediments. The datings presented in this paper are from the Younger Alluvium.

The near-perfect preservation of prior streams on the present Older Alluvium surface in some locations was first taken as evidence for a very youthful age. However, subsequent studies showed that they are of considerable antiquity, and regional stratigraphic studies confirm this.

Carbon samples occurring conformably in current bedded sands and gravels of stratigraphically the most recent prior stream beds, gave C14 age determinations of greater than 36,000 years (Pels, 1964*a*). This determination of age represented the limit of the dating equipment, so that it is not known how much older the sediments are.

On the other hand, Langford-Smith (1963) published dates of wood samples obtained from shallow depths in prior streams which indicated a much younger age. He attributed these dates to possible reactivation of prior stream beds during floods or root growth not related to the time of deposition.

Regional surveys (Pels, 1964*b*, 1966) have shown that the ancestral river system quite definitely post-dates the period of prior stream activity. This can be demonstrated generally over the Plain in N.S.W. and is substantiated by soils studies (Butler, 1958).

The two papers (Pels, *loc. cit.*) dealt with the surface configuration of the ancestral river system and subsurface geological aspects respectively. Both stressed the geochronological importance of movement along the Cadell Fault which enabled ready determination of three separate phases of river activity. It was shown that there is a non-diverted phase (Coonambidgal I) and two diverted phases (Coonambidgal II and III) and that each phase consisted of a degradational and aggradational sub-phase.

Carbon Datings

Datings of samples collected during the regional survey, which formed the basis of the two earlier papers, have now become available. Results of these datings substantiate the earlier postulations.

The radio-carbon datings were carried out by the Department of Nuclear and Radiation Chemistry of the University of New South Wales on samples obtained from sediments representing the three aggradational sub-phases, as follows.

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Coonambidgal I

This depositional system has a width of one mile and is clearly delineated on the Cadell Tilt Block near Wombootа. It is a filled-in river unaffected by further river activity because of movement along the Cadell Fault. It represents both a downcutting and infilling phase. A carbon sample was obtained from the centre of this system at a depth of 6′ 6″. It formed a layer of carbon conformably interbedded with thin layers of gravel. The site's location is :

Portion 16, Parish of Wombootа, County of Cadell, N.S.W.

Geographic co-ordinates : 35° 54′ S. ; 144° 41′ E.

Sample No. : 67/12 N.S.W. 31.

Age : Exceeding 28,600 years, i.e. beyond the limit of the equipment.

Coonambidgal II

It is known from stratigraphical evidence and the drastic diversion pattern of the ancestral river system near Mathoura (see Fig. 1) that this system again represents a downcutting phase with subsequent infilling. The fill is now represented by the higher older terrace along the Edward River at Deniliquin. The carbon sample, obtained from a borehole in this terrace, was a fragment of a knotted tree branch and definitely an aerial part. It was obtained from a depth of 40′ in State Forest No. 397, Parish of South Deniliquin, County of Townsend, N.S.W.

Geographic co-ordinates : 35° 32′ S. ; 144° 58′ E.

Sample No. : 67/14 N.S.W. 32.

Age : 24,050±835 years.

Coonambidgal III

There is a further distinct system of younger alluvium which can be traced adjacent to the Bullatale Creek between Tocumwal and Deniliquin. Near the latter town it becomes superimposed on the Coonambidgal II sediments associated with the Edward River. It now forms the lower terrace adjacent to the Edward River near Deniliquin (for details, see Pels, 1966, p. 34).

A deep trench was excavated across the lower terrace during construction of the Lawson siphon. This siphon, which was constructed to take irrigation supplies across the lower flood-plain (terrace) of the river, is restricted to this terrace and an elevated canal was constructed on the higher Coonambidgal II sediments.

The carbon sample was a block of wood cut out of a log encountered at a depth of 15′ during excavation. Its location is described as State Forest No. 397, Parish of South Deniliquin, County of Townsend, N.S.W.

Geographic co-ordinates : 35° 34′ S. ; 145° 01′ E.

Sample No. : 67/13 N.S.W. 33.

Age : 9,800±200 years.

The three datings indicate a definite chronological sequence. If the position of the Coonambidgal I sample within the sediments (6′ 6″ from the surface) were taken as an indication, it could be inferred that the age of greater than 28,600 years applies to the final stages of the infilling phase of Coonambidgal I.

The second date of 24,050 years would apply to the early stage of the infilling phase of Coonambidgal II (40′ from the surface) and the age of 9,800 years would also represent an early stage of infilling of Coonambidgal III. It is likely that the total phase of infilling occupied a considerable period of time.

This point is important when further correlations are attempted with other carbon datings from the region. From stratigraphical evidence the sequence of ancestral river activity of the Goulburn and Murray systems is visualized as shown in Fig. 1.

Bowler (1967) has published a date for ancestral river sediments associated with the Goulburn River near Shepparton showing an age of 30,600±1,300 years (N298).

It is known that the three phases are superimposed at this location, and the dated sediments would therefore represent Coonambidgal I. The sample from Wombootа (>28,600) could be of similar age, and this lends weight to the mapping of Coonambidgal I as shown in Fig. 1.

At the same location near Shepparton, younger sediments were dated as 26,200 and 24,500 years, and these dates again do not conflict with that determined for the Coonambidgal II near Deniliquin (24,050±835 years).

As can be seen from Fig. 1, the three phases are superimposed in some locations, but in others become laterally separated. Because of this, it was possible to establish (Bowler, 1967 ; Pels, 1966) that source-bordering sand dunes are common on the leeward side of Coonambidgal II ancestral rivers.

From this and other evidence, Bowler dated Coonambidgal II sediments at three further locations (samples N301, ANU29 and N296) (Bowler, 1967), which showed dates of 16,600±400, 13,500±700 and 13,400±340 years respectively.

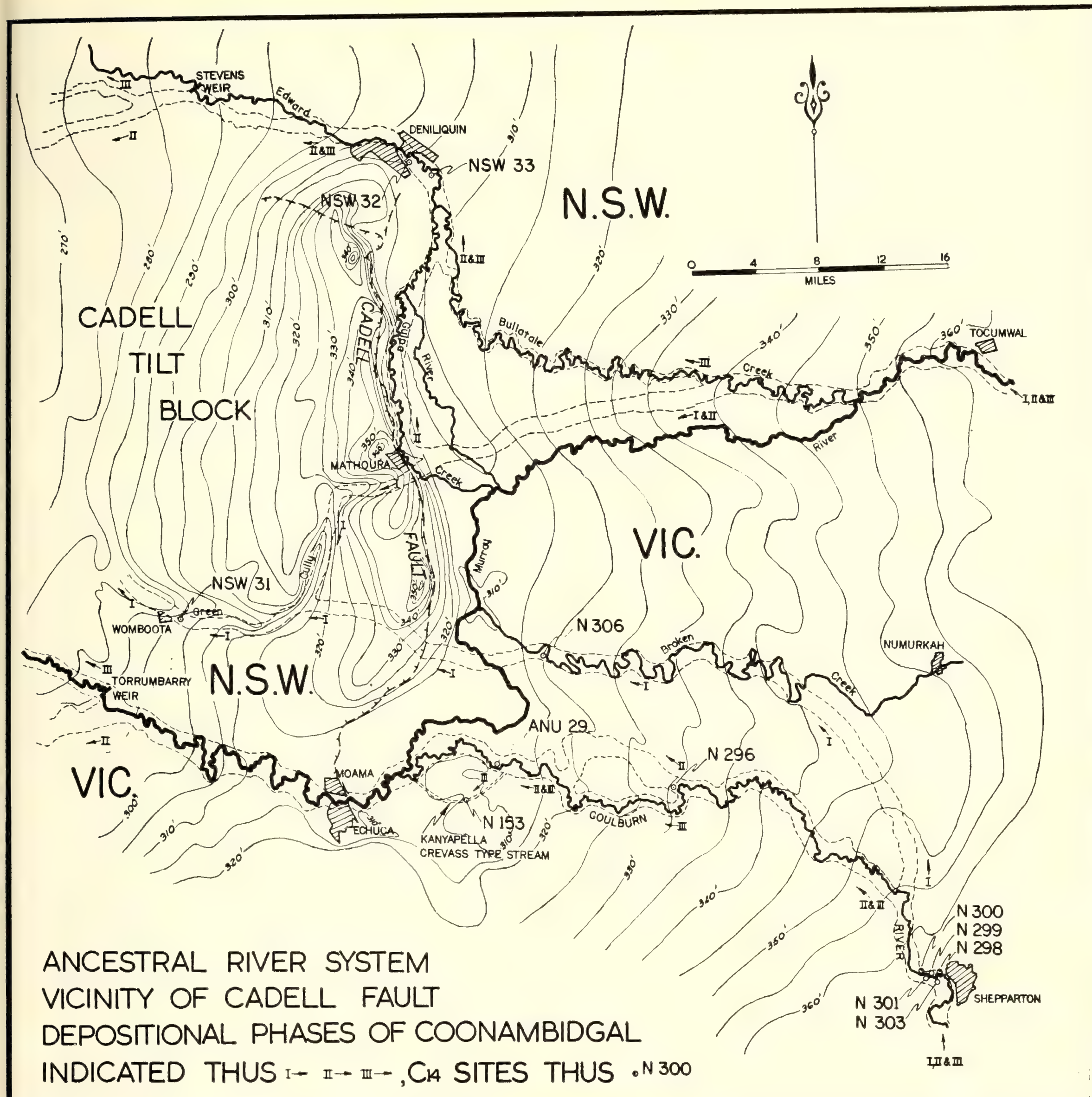

FIGURE 1.

The known dates of Coonambidgal II sediments therefore range from 26,200 to 13,400 years.

A further series of dates quoted by Bowler and ranging from 8,320±160 to 4,200±130 years appear to represent Coonambidgal III sediments of the Goulburn ancestral river system.

Bowler and Harford (1966) described sample N153 as having been derived from the Kanyapella prior stream. The present author suggests that this is a crevass-type stream which can be traced as leaving the final deposition of the third phase ancestral Goulburn (Coonambidgal III) and returning on to it as a continuous trace.

Except for the source-bordering sand dunes, deposition during the aggrading phases was generally restricted to the old river channel (valley fills in meandering valleys), but there

are isolated instances where crevass-type traces lead from, and return to, the aggraded ancestral river. Such stream traces also occur along the Billabong ancestral river (Pels, 1964*b*).

The age of the crevass-type Kanyapella stream sediments is 4,200 years (N153) and represents the final sedimentation of this phase. The combined dates therefore indicate that Coonambidgal III sedimentation took place between 9,800 and 4,200 years ago.

It should also be mentioned that in an extensive older alluvial environment the meandering valley walls may, in some locations, no longer be discernible, and this has given rise to confusion in the nomenclature used in papers on the Riverine Plain's geomorphology. One instance of this is the naming of the " Tallygaroopna prior stream " in the Goulburn Valley by Bowler. This is clearly a deserted ancestral river and is again described as such in a later paper by the same author (Bowler, 1967).

The only dating which does not fit in with the discussion so far and the sequence depicted in Fig. 1 is Bowler's N306 age determination, which, from the locations description, should represent Coonambidgal I (see Fig. 1). In view of the dates obtained from Womboota and Shepparton the age indicated by this sample, $20{,}900 \pm 500$ years, is not acceptable as it is now known that this phase was diverted prior to at least 26,000 years B.P., as indicated by the age of sample N299 from Coonambidgal II sediments near Shepparton and by sample NSW32 from phase II sediments near Deniliquin. The younger date of sample N306 could be accounted for by root growth at that time.

Interpretation

The correlation of carbon datings with events which created the present configuration of alluvial sediments can only be tentative. However, sufficient information is now available to warrant an attempt to draw up a geochronology and to draw from it palaeoclimatological inferences.

This information includes, apart from the C14 datings,

(i) the clear diversion pattern of ancestral rivers around the Cadell Fault,
(ii) the readily recognizable surface expression of these former river systems,
(iii) the widely separated independent courses of the river in some locations and superimposition in others.

In earlier papers it has been stated that downcutting of a river channel is thought to occur under relatively pluvial conditions and infilling under more arid conditions. This is the majority of opinion in the world literature on climatically-induced terrace levels of misfit rivers. Recent work by Schumm (1966) gave similar conclusions from morphological studies of ancestral river and present-day river channels of the Murrumbidgee River. Whitehouse (1940) discussed the common occurrence of three terraces along the major rivers in Queensland. Taylor and England (1929) described three terrace levels with differing soil development along the lower Murray River near Renmark.

By applying the same reasoning to these investigations, it has been inferred that the three aggrading phases took place under more arid conditions and that the last phase concluded approximately 4,000 years ago.

The present river represents a further downcutting phase. It is to be noted that the three phases were of decreasing intensity, as shown by the dimensions of the respective ancestral rivers.

Figure 2 shows, in diagrammatic form, how the sequence of events is visualized.

Before any carbon datings were carried out, there was evidence to suggest that a recurring process of degradation and aggradation occurred. Carbon datings have now supplied corroborating evidence and have given some indication of the time spans involved in these sequences.

Present results are at variance with conclusions by Bowler (1967), who states: " These two drainage systems (Coonambidgal I and II) are seen rather as part of one single phase of high discharge during glacial times. The notion that tectonic interruption occurred just at the conclusion of one pluvial-arid cycle and before the beginning of another, is not yet substantiated."

It is reiterated that a fully aggraded river channel (Green Gully) was tectonically uplifted and that the subsequently newly created diverted ancestral river now also forms a deeply incised and subsequently filled channel, thus indicating that consecutive pluvial-arid phases were responsible.

Recurring climatic fluctuations can be traced further back into the geological history of the Plain.

Sections bored through prior streams (Pels, 1964*a*) commonly show a distinct vertical break from sand and gravel at the bottom of the stream bed to heavy clay. This abrupt break, together with characteristic shapes of incised channels, indicates that prior stream phases also com-

menced with downcutting which was followed by aggradation. However, unlike ancestral rivers this aggradation was not restricted to the incised channels but eventually extended beyond the channel banks by lateral overtopping, giving rise to widespread lateral distribution of stream bed, levee and floodplain sediments so typical of prior streams.

limited drainage at that time from the region. It appears to have been a large inland area of sediment accumulation.

The extensive nature of the prior stream systems and the large quantities of sediments involved indicates that large-scale erosion in the highlands and deposition on the Plain were parallel processes.

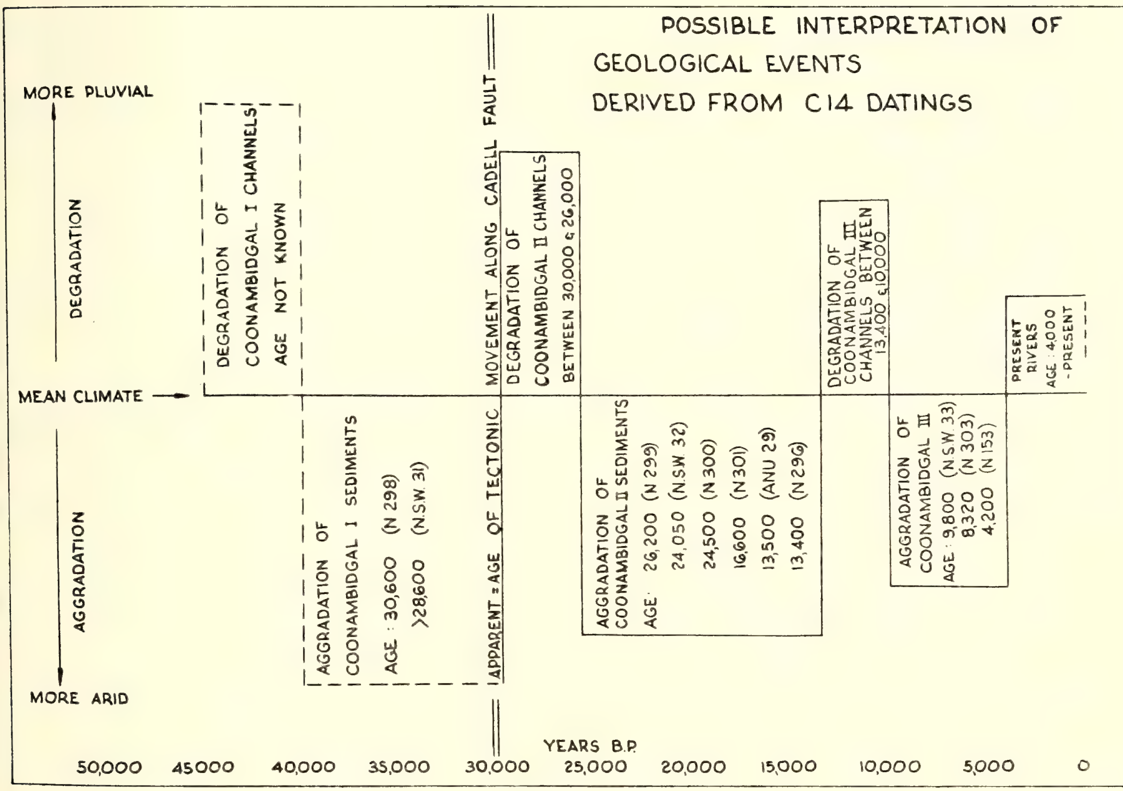

FIGURE 2.

The pattern of prior streams over the plain is not visualized as having been actively depositing simultaneously, and several phases of deposition and diversions to lower lying areas are probably responsible for the present distributary pattern of prior stream traces (see Fig. 3).

The definite change from prior streams to ancestral rivers warrants further consideration. It represents a major change in the drainage system of the region.

The distributary pattern of prior streams over the Plain and its dissipating nature towards the west suggests that there was very

This is in contrast with evidence shown by ancestral rivers. From the general occurrence of terraces along the entire river, it is clear that the process of degradation (and later aggradation) was synchronous along the entire river course. Terraces are common along the Murray River in the upper reaches and also in South Australia. Where they are absent in the central sector, they have been accounted for as deserted floodplains.

Furthermore, the prior streams form a distributory pattern, while ancestral rivers form a tributary system (Fig. 3).

Such an overall change in the behaviour of rivers and streams suggests a drastic change in

FIGURE 3.—The Riverine Plain in New South Wales.
(Drawn by W. Mumford, A.N.U.)

the drainage system of the Plain and there is evidence to substantiate such a postulation. The western fringe of the Riverine Plain consists predominantly of heavy-textured fluviatile sediments, indicating semi-lacustrine conditions of deposition and evaporite accumulation. It contains numerous lake and lunette relicts and Mallee outliers. Prior stream patterns generally dissipate before reaching this zone.

Surface water penetrated the lower lying areas of the Mallee, and chains of lakes are known to have occurred where the present Murray course is now located. There are remains of lunettes adjacent to the river, and

preserved lakes occur in its vicinity. The great chain of lakes at the end of Willandra Creek, which branches off the Lachlan River near Hillston, forms a similar set of landscape conditions.

The absence of older alluvial (prior stream) sediments along the Murray River west of Wakool Junction suggests that this is a " post-prior stream " course which now drains the area.

The creation of this drainage channel from the region would account for the change-over from a distributory-prior stream system to a tributary ancestral river system, and would explain the present rivers of transit being unrelated to the Plain's surface sediments. It further explains the increasing salt status of the Riverine Plain's soils towards the west and the occurrence of an otherwise anomalous vast area of alluvial deposition along, what is now, the middle reach of the Murray River system.

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Note on Coals Containing Marcasite Plant Petrifactions, Yarrunga Creek, Sydney Basin, New South Wales

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Abstract—Coals of low bituminous rank, resembling in type a coal from the Clyde River Coal Measures, contain numerous plant petrifactions of marcasite with minor pyrite. The iron sulphides were emplaced early in the history of the coal and are associated with vitrinite-rich layers. They have replaced plant tissue rather than filled up voids in the peat. Massive marcasite is thought to represent complete replacement, whereas the material with relict plant structure may represent an intermediate stage.

Introduction

The coal measures at Yarrunga Creek were discovered in 1967 by geologists of the Metropolitan Water, Sewerage and Drainage Board during site investigations along the Kangaroo River (Gray, 1969). The location of the occurrence is shown in Figure 1, and the stratigraphic column in Table 1. The characteristics of the coals are of interest, as this occurrence forms one of the most extensive developments of coal measures near the base of the Shoalhaven Group. The coals have unusually large amounts of iron sulphides which contain plant petrifactions.

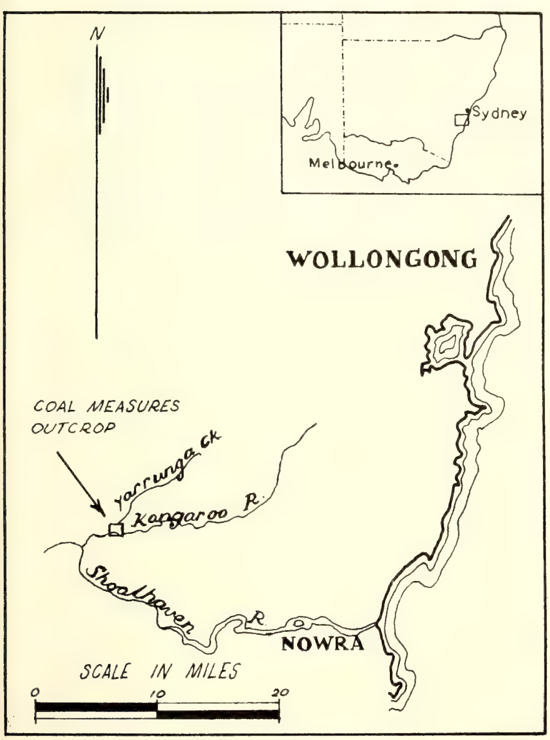

Figure 1.—Locality map.

Table 1

		Thickness (Feet)
Permian	Conjola Formation—sandstone	200+
	Coal measures—sandstone shale with coal seams	0–50
	Sandstone and conglomerate . .	200+
Basement	Older Palaeozoic Rocks	

Table 2

Petrographic Composition and Sulphur Content of Coal Seams

	Site A			Site B
	Bore 1 Seam A	Bore 4 Seam A	Bore 1 Seam B	Bore 3
Thickness . .	3′ 9″	5′ 6″	1′ 5″	2′ 7″
Petrographic analysis :				
Vitrinite . .	56	34	39	56
Exinite . .	2	3	1	6
Micrinite . .	19	24	15	12
Semifusinite	15	24	19	19
Fusinite . .	2	2	2	2
Mineral matter	6	13	24	5
Total . .	100	100	100	100
Sulphur content (approx.)	4%	8%	4%	2%*

* On floats at 1·60 specific gravity.

Petrography of Coals

The coals are generally similar in appearance to the Clyde River Coal Measures coal described by Cook and Read (1968). In hand-specimen they are mainly dull, or finely laminated, dull and bright, but contain a few bright lenses over 2 mm. in thickness.

The maceral analyses (Table 2) show that considerable variations in petrographic composition occur. Much of the vitrinite occurs in intermediate microlithotypes rather than as vitrite. Exinite is present as microspores, resin bodies and leaf cuticles. The mineral matter is mainly clay, quartz, marcasite and pyrite.

Reflectance measurements on vitrinite samples from two bores gave an average mean value of 0·85%, which is equivalent to a carbon content of 83–84% (d.m.m.f.). The rank is therefore similar to that found for the Clyde River Coal Measures coal by Cook and Read (1968). It is also similar to the rank of coals in the Illawarra Coal Measures in the extreme south-west of the South Western Coalfield (Cook and Wilson, 1969). Unfortunately as yet there are no rank data available for both the Illawarra Coal Measures and the base of the Shoalhaven Group at the one locality.

Marcasite and Pyrite

Abundant lenses and nodules, up to 3 cm. long and 0·5 cm. thick, of iron sulphides are present. Chemical analysis of a hand-picked sample of sulphide gave Fe 36·2%, S 40·9%, ignition loss 22·0%, with minor traces of Si, Ni, Co, Al, Cr, Mn and Mg. Assuming the ignition loss corresponds to coal, the sulphur-to-iron ratio is 1·97.

The iron sulphides occur chiefly in the brighter coal lenses and are associated with vitrinite. Some lenticular chalcedony plant petrifactions were also noted near sulphide lenses. The iron sulphides are an intimate mixture of marcasite and pyrite with the marcasite being the dominant phase. The marcasite and pyrite occur as plant petrifactions, showing transitions from well-preserved uncrushed cell structure (Plate I) to crushed and disordered cell structure. There are also transitions to massive replacements lacking evidence of plant structure (Plate II). The petrifactions are similar to those figured on cards 45–48 in *Bildkartei der Erzmikroskopie* (1961). This type of petrifaction has not been recorded previously from coals in the Sydney Basin. The relationship of the sulphide lenses to the surrounding and included coal provides some evidence as to the mode of emplacement.

The boundaries between the vitrinite and the sulphide lenses are discordant, with marked compaction structures being present in the surrounding coal. However, the plant structures visible at the edges of the sulphide masses indicate that the plant structures in them were originally continuous with those of the surrounding vitrinite.

The plant cell structures in the marcasite are rendered visible by the presence of remnants of organic material preserved as vitrinite. These vitrinite fragments are typically in the range of 0·5 to 5 microns and represent partially replaced secondary walls and middle lamellae. Pit structures are still preserved in some examples, and it appears that in general the middle lamellae are more extensively replaced than the secondary cell walls. The cell lumens are usually completely replaced by marcasite, but in some lumens (Plate III) embayed remnants of vitrinite are present. A different, though possibly related phenomenon, is the presence in some cell lumens of material which is optically homogeneous but which has a lower reflectivity and polishing hardness than the surrounding marcasite (Plate III). It is thought that this represents incomplete replacement of plant material with the particle size of the organic material being too small to be resolved optically.

The marcasite and pyrite grain boundaries commonly show some control by the plant cell structure (Plate I). Individual cell lumens generally consist of a small number of crystals, while many lumens consist of a single crystal. However, some crystals cover a number of cell lumens. In the massive structureless marcasite, grain boundaries give no indication of previously existing cell structure, although surrounding or included cell structure strongly suggests that it was originally present.

The uncrushed nature of much of the plant structure indicates that mineralization must have occurred relatively early in the development of the coal. The presence of embayed vitrinite in some cells and a possible marcasite-vitrinite mixture in others makes it probable that the marcasite in the cell lumens generally replaced organic material rather than filled up voids in the plant tissue. It appears that the precipitation of the sulphide phase was controlled by a favourable chemical environment rather than by space considerations. Indirect confirmation of this is to be found in the absence of marcasite from cell lumens in semifusinite. The cell lumens of the semifusinite would probably have been empty or only incompletely filled by clay and quartz at the time of the

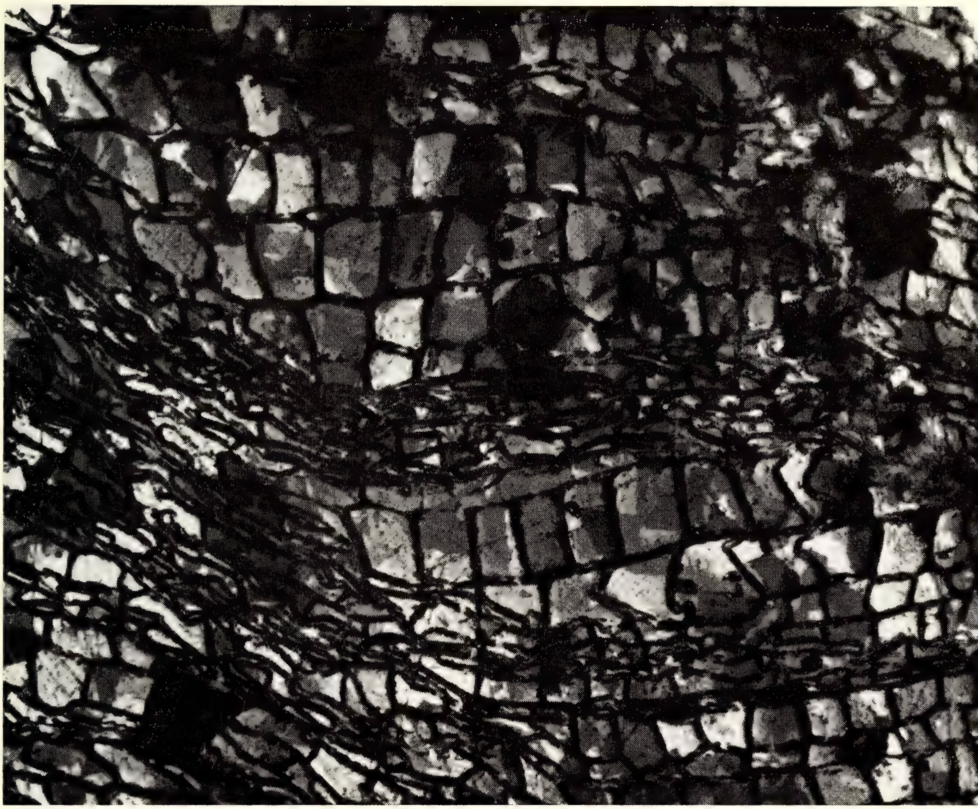

PLATE I.—Plant cells preserved as marcasite petrifactions. Reflected light, oil immersion, crossed nicols. $\times 230$.

PLATE II.—Massive marcasite with minor pyrite. Cell structure is present on the right-hand margin of the field of view. Reflected light, oil immersion, crossed nicols. $\times 230$.

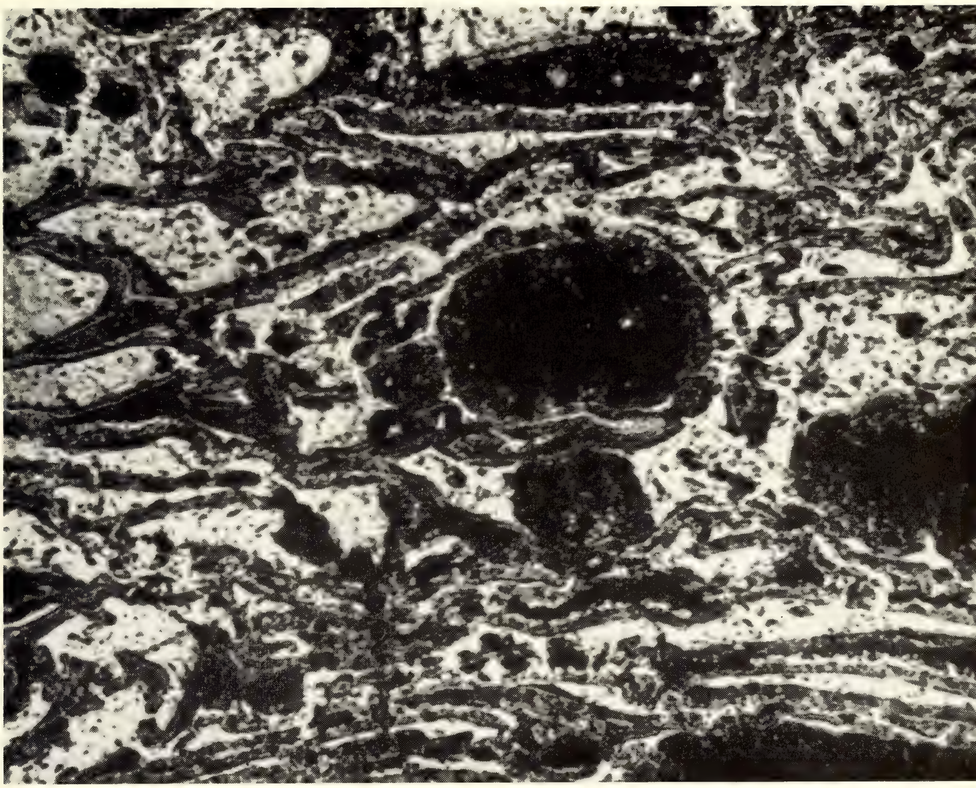

Plate III.—Vitrinite (black) occurring as partially replaced cell walls and cell lumens. The marcasite (white) has a lower reflectance and polishing hardness than that shown in other figures and may represent a marcasite-vitrinite mixture at a submicroscopic scale. Reflected plane polarized light. ×630.

formation of the marcasite. The relation of the massive sulphide to the sulphide-containing relict cell structures indicates that the structured phase represents an intermediate stage with the massive phase resulting from complete replacement of the plant material.

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Meson Field Potential in Fundamental Theory

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Abstract—It is shown that Yukawa's potential of a meson field can be generated within Eddington's Fundamental Theory.

In this note we shall discuss a method of deriving a formula for the meson field potential in Fundamental Theory of Eddington (1946). Eddington himself maintained that the formula must be given by a Gaussian distribution

$$\exp\left(-A(r-r_0^2)\right), \quad A>0. \quad \ldots. \quad (1)$$

To correct his mistake, Kilmister and Tupper (1962) considered the expectation value ψ of the potential per unit charge with a Gaussian distribution function. Defining a non-Coulombian potential ψ_1 by

$$\psi_1=\frac{1}{r}-\bar{\psi}(r), \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

they found a remarkable approximation

$$\psi_1\approx\frac{1}{r}\exp\left(-1\cdot 17r/25\right). \quad \ldots\ldots \quad (3)$$

The error was $<0\cdot 004$ for $0<r<1\cdot 5/\sqrt{A}$.

The formula (3) is, of course, of the form of a Yukawa potential. It seems, however, that there is little connection between the above result and the argument of Fundamental Theory. In the latter, a meson is a decaying object associated with the transition from an unrestricted energy state (presumably, of an atomic nucleus) to a stable, symmetric configuration (Klotz, 1969). This can be regarded as a scattering experiment in which the scattering agent is a spherically symmetric, impenetrable region of the ordinary three-dimensional space and radius r_0. It is essential for the scattering centre to be represented as if it had no field of its own, since the stabilization process of Fundamental Theory has no location in the physical space-time. The "impinging" particle is then equally likely to be anywhere within $r>r_0$, but it cannot penetrate into the region $r<r_0$.

Let us consider now the conditional probability P_c of an event $u>x+dx$, whenever $u>x$. If the frequency function of u is f,

$$P_c=\frac{\text{Probability }(u>x+dx)}{\text{Probability }(u>x)}=1-\frac{f(x)dx}{\int_x^\infty f(z)dz} \quad \ldots\ldots\ldots\ldots \quad (4)$$

Suppose now that no additional information is to be derived from $u>x+dx$ as long as $u>x$. Then

$$(1-P_c) \text{ is proportional to } dx. \quad \ldots \quad (5)$$

Hence we can write

$$f(x)=\alpha\int_x^\infty f(z)dz \quad \ldots\ldots\ldots\ldots \quad (6)$$

where α is a constant. For continuous and differentiable f, therefore,

$$f(x)=f_0\exp(-\alpha x).$$

Since f is a distribution,

$$\int_0^\infty f dx=1=f_0/\alpha.$$

Therefore

$$f(x)=\alpha\exp(-\alpha x). \quad \ldots\ldots\ldots \quad (7)$$

If we associate the above probability distribution with a charge (electrical or mesonic as the case may be), the potential must be a function of the form

$$q(x)/x \quad \ldots\ldots\ldots\ldots \quad (8)$$

Hence, when q has the frequency distribution (7) we obtain a Yukawa potential

$$\frac{q_0\exp(-r/r_0)}{r}. \quad \ldots\ldots\ldots \quad (9)$$

This shows that it is possible to set up probabilistic hypotheses within Fundamental Theory, which conform to the known facts relating to the meson fields. Eddington's Gaussian distribution now relates only to the connection between cosmology and quantum scale physics.

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The Energy Storage of a Prescribed Impedance*

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Abstract—The problem of inferring the total average energy storage of a passive linear electrical impedance from its observed or specified terminal behaviour alone is discussed. Only in a few special cases is the energy storage (for sinusoidal external excitation) uniquely determinable.

A general expression for the energy storage is derived which involves, in addition to terminal properties, properties of a set of functions describing the separate dissipative processes. This expression is used to find a new minimum energy storage for a lumped-element network which all realizations of the impedance must equal or exceed. There exists a minimum energy synthesis storing minimum energy at all frequencies, which corresponds to minimum phase shift Darlington synthesis of the impedance. This minimum energy storage synthesis can be realized provided gyrators can be employed.

I. Introduction

When a linear passive network is excited sinusoidally there is generally a storage of electromagnetic energy by the reactive elements. Assuming the terminal behaviour is known, the question may be asked : to what extent is the physical energy storage of the network determined by the terminal behaviour ? Alternatively : what can be inferred about the energy storage of a network from measurements of its terminal behaviour alone ? To be specific, we consider the impedance $Z_0(p)$ of a hypothetical linear, passive one-port to be given for all $p=i\omega$, and examine the possible corresponding energy storage from excitation by a r.m.s. current I_0.

If $Z_0(p)$ is a pure reactance, it is well known (Bode, 1945, sec. 9.4 ; Maa, 1943 ; Montgomery *et al.*, 1948 ; Pannenborg, 1952) that the energy storage for a given sinusoidal excitation is uniquely determined. Also, if $Z_0(p)$ is known to result from a reciprocal network containing only two kinds of elements the energy storage is also easily shown to be unique (Section III). However, it can be seen that in the general case the energy if not fixed by $Z_0(p)$ alone. Suppose we have a particular network realization of $Z_0(p)$ which is assumed not to be a pure reactance. Then any resistance in this realization which is dissipating power may be replaced by an all-pass network terminated in a resistance, or some other combination of reactive and resistive elements which behaves terminally as a resistance (e.g. Cauer, 1958, p. 53), without changing the terminal behaviour $Z_0(p)$ of the network as a whole. (If distributed circuits are introduced each resistance may be replaced by a loss-free transmission line of arbitrary length terminated by its characteristic impedance). Although $Z_0(p)$ is unchanged by this transformation, the energy storage is changed (increased) by the introduction of additional reactive elements.

Thus it becomes clear that the energy storage of a system described by the general impedance $Z_0(p)$ depends upon aspects of the internal structure of the network, in striking contrast to the purely reactive case. In other words the energy depends upon the particular realization of $Z_0(p)$, and terminally equivalent networks are not necessarily equivalent as far as energy storage is concerned.

By the above procedure it is possible to increase the energy storage associated with a specified dissipative impedance $Z_0(p)$. This suggests the existence of either a minimum possible energy storage at a particular frequency or a minimum energy realization over all frequencies. Both of these conjectures are shown to be true. For systems containing no non-reciprocal elements (as typified by gyrators) a simple lower bound exists for the energy (see Section III) at any frequency $p=i\omega$.

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However, if non-reciprocal (i.e. gyrator-like) behaviour is exhibited by the network this minimum energy expression is not applicable (Smith, 1967), and a lower energy may sometimes be possible. In Section VII the minimum possible energy is found and it is shown that a minimum energy realization by Darlington synthesis is always possible provided gyrators are employed. The natural requirement for gyrators to obtain the minimum energy network is somewhat curious but it is demonstrated that in general they are essential.

In Sections II and III some elementary observations on equivalent circuits and particular results for special cases are noted. In Section IV general expressions are obtained for the energy storage which involve internal functions associated with the energy dissipation. For the special case of a reciprocal network for which $Z_0(p)$ is specified as a function of the magnitudes of the individual resistances, Vratsanos' theorem may be employed to deduce the energy uniquely (Section V).

The energy storage of networks with one resistor is treated in Section VI. This case, although special in itself, occupies a central role in showing the existence of a minimum energy and a minimum energy storing network (Sections VII and VIII). In Section IX a very simple example is discussed at length to illustrate points in the main body of the paper. The discussion is oriented towards lumped-element systems because this is where synthesis methods are available, but much of it is not necessarily restricted to this case only. Energy storage is interpreted to mean the total average physical energy storage resulting from the excitation. In a complex system this may not be entirely electromagnetic energy ; for example T and V might both contain a mechanical energy component in a dispersive system (Smith, 1967). The microscopic distinction (Tonning, 1960) between purely electromagnetic and other forms of energy is not made here.

II. Some Remarks on Equivalent Circuits

The term equivalent circuit is well entrenched in the literature with the meaning of equivalent terminal behaviour or equivalent with regard to exterior behaviour. We have seen in I that equivalent circuits in this sense need not have the same energy storage. Objections to the use of the term " equivalent " to apply to the terminal behaviour alone have been made before and Gross and Braga (1961) have suggested the use of " pseudo-equivalent " to emphasize the terminal equivalence only. The use of the term " internally equivalent " is suggested to imply not only equivalence in the usual sense but also that internally equivalent networks have the same average magnetic (kinetic) and electric (potential) energy storages T, V and power dissipation P for similar excitation. The need for the specification of both T and V rather than the total energy $(T+V)$ arises because of further complications with non-reciprocal (gyrator containing) networks. It is easily shown (Balabanian, 1958, sec. 1.6, 1.7) for reciprocal networks that

$$I_0^* I_0 Z_0(i\omega) = 2i\omega(T-V)+P \quad \dots\dots\dots\dots \quad (1)$$

where I_0 is the r.m.s. excitation current of Z_0 at $p=i\omega$. Thus

$$T-V = I_0^* I_0 X_0(i\omega)/2\omega \quad \dots\dots\dots\dots \quad (2)$$

so that for a specified impedance T and V are both fixed when the total energy $W=T+V$ is known. Thus reciprocal equivalent networks having the same total energy are internally equivalent.

However, since Eq. (2) is inapplicable to gyrator-containing networks (Smith, 1967), the same total energy does not imply the same T and V for a given impedance.

The term equivalent network was also used by Cauer (1958, Chap. 10) in describing a transformation which formed a set of networks having the same terminal behaviour. We shall show that Cauer's equivalent networks are also internally equivalent.

Suppose the n mesh equations of a reciprocal network are

$$\mathbf{ZI}=\mathbf{V} \quad \dots\dots\dots\dots \quad (3)$$

$$\mathbf{V}=\begin{pmatrix} V \\ 0 \\ 0 \\ 0 \end{pmatrix} \quad \dots\dots\dots\dots \quad (4)$$

where V is the voltage source exciting the network in the first mesh only and $\mathbf{I}$ is the mesh current vector. $\mathbf{Z}$ has the form

$$\mathbf{Z}=p\mathbf{L}+\mathbf{R}+\mathbf{D}/p \quad \dots\dots\dots\dots \quad (5)$$

where $\mathbf{L}$, $\mathbf{R}$, $\mathbf{D}$ are constant real symmetric matrices. The Cauer transformation transforms the mesh currents $\mathbf{I}$ to $\mathbf{I}'$ through the non-singular, real, constant, transformation $\mathbf{T}$

$$\mathbf{I}=\mathbf{T}\mathbf{I}'. \quad (6)$$

If $\mathbf{T}$ is required to have the first element of the first row equal to 1 and all other elements in the first row zero, Cauer shows that an n mesh network having the mesh impedance matrix

$$\mathbf{Z}'=\mathbf{T}^T\mathbf{Z}\mathbf{T} \quad (7)$$

will be an equivalent network.

For $p=i\omega$ it is easily seen that the energy of the original network is given by

$$\begin{aligned} 2W=2(T+V) &= \mathbf{I}\dagger(\partial\mathbf{Z}/\partial p)_{p=i\omega}\mathbf{I} && (8)\\ &= \mathbf{I}'\dagger\mathbf{T}^T(\partial\mathbf{Z}/\partial p)_{p=i\omega}\mathbf{T}\mathbf{I}' \text{ (from (6) and } T \text{ real)} && (9)\\ &= \mathbf{I}'\dagger[\partial/\partial p(\mathbf{T}^T\mathbf{Z}\mathbf{T})]_{p=i\omega}\mathbf{I}' \ (T \text{ constant}) && (10)\\ &= \mathbf{I}'\dagger(\partial\mathbf{Z}'/\partial p)\mathbf{I}' \text{ (from (7))} && (11)\\ &= 2(T'+V')=2W' && (12)\end{aligned}$$

where $W'=T'+V'$ is the total energy of the equivalent network for the same excitation. Since we are considering only reciprocal networks, this implies that the Cauer equivalent networks are internally equivalent.

III. Energy Storage in Simple Cases

Two elementary cases where the energy storage is unique are reviewed. Another special case will be discussed in Section V after general expressions for energy storage are derived.

(a) *Loss-free Networks*

For loss-free networks, i.e. $Z_0(p)$ a reactance function, the energy storage is given uniquely by (Bode, 1945, sec. 9.4; Maa, 1943; Montgomery *et al.*, 1948).

$$W=T+V=\tfrac{1}{2}I_0^*I_0(\partial Z_0/\partial p)_{p=i\omega}. \quad (13)$$

Bode remarks that Eq. (13) implies that the total volt ampere rating of the elements in a reactance network is independent of the manner of synthesis. Thus from (13) and (1) the following proposition applies for reciprocal networks. All equivalent reciprocal reactance networks are internally equivalent. For non-reciprocal networks Eq. (13) for the total energy still applies (Tonning, 1960 ; Smith, 1965 ; Carlin, 1967), so that equivalent reactance networks store the same total energy. However, because Eq. (1) no longer applies this does not imply equality of the magnetic and electric energies separately.

(b) *RL and RC Circuits and a Simple Bound for Reciprocal Networks*

If the network is known to be reciprocal, Eq. (1) applies. Further, if it is also known to be either an RL or RC network, V or T respectively is zero and Eq. (1) gives

$$|T+V|=|T-V|=I_0^*I_0|X_0|/2\omega. \quad (14)$$

Notice that it is not sufficient for $Z_0(p)$ to be of a form for RL or RC synthesis to be possible (e.g. Balabanian, 1958, sec. 2.3, 2.4). The network itself must actually be an RL or RC synthesis of $Z_0(p)$. When this is the case, Eq. (14) shows that the energy storage is again independent of the details of the network synthesizing $Z_0(p)$. For example, the two Cauer canonical forms and the two Foster forms (Balabanian, 1958) will all store the same energy, and this will be the same as for any other two-element kind synthesis.

Thus the problem of energy storage for two-element kind reciprocal networks or for loss-free non-reciprocal networks is easily solved uniquely. For reciprocal RLC networks Eq. (1) may still be used to give a bound on the energy at any particular frequency

$$|T+V|\geq|T-V|=I_0I_0^*|X_0|/2\omega. \quad (15)$$

For RL and RC networks this bound is attained at all frequencies. This bound is not applicable to non-reciprocal networks, and it will be shown in Sections VII and VIII that the absolute minimum energy storage may well be less than that given by (15).

IV. General Expressions for the Energy Storage

It will be shown that the average energy storage may be written in terms of the reactive behaviour of the impedance, and a set of causal frequency-dependent functions describing the several dissipative processes. The energy storage expression may be obtained conveniently in two ways : (i) by writing out circuit equations so as to treat the network as a reactive n-port, the energy storage of which is known (Maa, 1943), together with the resistors causing the dissipation ; (ii) by considering energy conservation for a terminal excitation exp $(i\omega+\sigma)t$ with $\sigma\to 0$.

The first type of argument has been used by Kishi and Nakazawa (1963) in their paper relating group delay and energy storage. The second method, an adaptation of the methods of Cauer (1958, Chap. 4) for proving the positive real character of impedance functions has been used by Tonning (1960) and Carlin (1967) to find the energy storage of reactances. This method has the virtue of being independent of the nature of the system and is not restricted to lumped-element or reciprocal systems.

Suppose the impedance $Z_0(p)$ is excited by a current which has the instantaneous value

$$\mathscr{I}_0=\mathrm{Re}\,\{\sqrt{2}I_0\exp pt\} \quad \ldots\ldots\ldots\ldots \quad (16)$$

with

$$p=i\omega+\sigma, \qquad \sigma>0 \quad \ldots\ldots\ldots\ldots \quad (17)$$

The instantaneous voltage across the impedance is then

$$\mathscr{V}_0=\mathrm{Re}\,(\sqrt{2}Z_0(p)I_0\exp(pt)). \quad \ldots\ldots\ldots\ldots \quad (18)$$

Since the only sources of energy dissipation in the impedance are the resistances, we can write the following instantaneous energy conservation equation

(Power supplied by the excitation) = (Power used to increase energy storage in the impedance)
+(Power dissipated in the resistors). .... (19)

The impedance is supposed to be in the quiescent state (zero energy storage) at $t=-\infty$. To find the energy stored at time t_0 for this excitation, we must integrate Eq. (19) from $t=-\infty$ to $t=t_0$.

(total energy supplied by the excitation) = (energy stored by the network)
+(energy dissipated by the network) .. (20)

We now introduce the functions $f_k(p)$,

$$f_k(p)=I_k(p)/I_0 \quad \ldots\ldots\ldots\ldots \quad (21)$$

where $I_k(p)$ is the complex current in the k^{th} resistor R_k for the excitation (16). I.e.

$$\mathscr{I}_k=\mathrm{Re}\,\{\sqrt{2}I_k(p)\exp pt\} \quad \ldots\ldots\ldots\ldots \quad (22)$$
$$=\mathrm{Re}\,\{\sqrt{2}f_k(p)I_0\exp pt\}$$

is the instantaneous current flowing in the k^{th} resistor. Notice that the current $\mathscr{I}_k$ is causally derived from the excitation current, so $f_k(p)$ is a transfer function analytic in the right half of the p plane. This analyticity extends on to the imaginary p axis since the dissipation in each resistor must remain finite for finite I_0. $f_k(p)$ is also a real function of p.

If $\mathscr{W}(t_0)$ is the energy storage at time $t=t_0$, Eqs. (19) and (20) become

$$\mathscr{V}_0\mathscr{I}_0=\mathrm{d}\mathscr{W}/\mathrm{d}t+\sum_k \mathscr{I}_k^2R_k \quad \ldots\ldots\ldots\ldots \quad (23)$$

$$\int_{-\infty}^{t_0}\mathscr{V}_0\mathscr{I}_0\,\mathrm{d}t=\mathscr{W}(t_0)+\sum_k R_k\int_{-\infty}^{t_0}\mathscr{I}_k^2\,\mathrm{d}t \quad \ldots\ldots\ldots\ldots \quad (24)$$

i.e.,

$$2\int_{-\infty}^{0}\mathrm{Re}\,\{Z_0(p)I_0\exp(pt)\}\,\mathrm{Re}\,\{I_0\exp(pt)\}\mathrm{d}t$$
$$=\mathscr{W}(t_0)+2\sum_k R_k\int_{-\infty}^{t}[\mathrm{Re}\,\{f_k(p)I_0\exp(pt)\}]^2\mathrm{d}t \quad .. \quad (25)$$

i.e.

$$\int_{-\infty}^{t_0} e^{2\sigma t}\,\mathrm{Re}\,\{Z_0(p)I_0^2 e^{2i\omega t}+I_0 I_0^* Z(p)\}\mathrm{d}t$$
$$=\mathscr{W}(t_0)+\sum_k R_k\int_{-\infty}^{t_0} e^{2\sigma t}\,\mathrm{Re}\,\{[f_k(p)I_0]^2 e^{2i\omega t}$$
$$+f_k(p)f_k^*(p)I_0I_0^*\}\mathrm{d}t. \quad\ldots\ldots\ldots\ldots (26)$$

Performing the integration and dropping the subscript on t_0, we obtain

$$e^{2\sigma t}\,\mathrm{Re}\,\{Z_0(p)I_0^2 e^{2i\omega t}/2(\sigma+i\omega)+Z(p)I_0I_0^*/2\sigma\}$$
$$=\mathscr{W}(t)+\sum_k R_k e^{2\sigma t}\,\mathrm{Re}\,\{(f_k(p)I_0)^2 e^{2i\omega t}/2(\sigma+i\omega)+f_k(p)f_k^*(p)I_0I_0^*/2\sigma\}. \quad\ldots\ldots (27)$$

The energy corresponding to sinusoidal excitation $p=i\omega$ is obtained from Eq. (27) by considering its limiting form as $\sigma\to+0$. The average energy is then obtained by averaging over a full cycle $2\pi/\omega$. The terms requiring special consideration are those having 2σ as denominator. Write

$$Z_0(p)=R_0(p)+iX_0(p). \quad\ldots\ldots\ldots\ldots (28)$$

Then for small σ, $Z_0(p)$, being analytic, may be expanded as a Taylor series about $p=i\omega$ provided $p=i\omega$ is not a pole of $Z_0(p)$.

Then

$$R_0(i\omega+\sigma)=R_0(i\omega)+(\partial R_0/\partial\sigma)_{p=i\omega}\,\sigma \quad \text{to first order in } \sigma. \quad\ldots\ldots\ldots (29)$$

Further, $f_k(p)$ is also analytic, so

$$f_k(p)f_k^*(p)=f_k(i\omega)f_k^*(i\omega)+\sigma\frac{\partial}{\partial\sigma}(f_kf_k^*)_{p=i\omega} \quad \text{to first order in } \sigma. \quad\ldots\ldots\ldots (30)$$

Furthermore, in the steady harmonic state the total dissipation $I_0I_0^*R_0(i\omega)$ is equal to the sum of the powers dissipated in the individual resistances R_k. I.e.

$$I_0I_0^*R_0(i\omega)=\sum_k R_kf_k(i\omega)f_k^*(i\omega)I_0I_0^*. \quad\ldots\ldots\ldots (31)$$

After substituting (29), (30), (31) in (27), the limit $\sigma\to 0$ may be taken to give

$$\mathrm{Re}\,\{Z_0(i\omega)I_0^2e^{2i\omega t}/2i\omega\}+\tfrac{1}{2}I_0I_0^*(\partial R_0/\partial\sigma)_{p=i\omega}$$
$$=\mathscr{W}(t)+\sum_k R_k[\mathrm{Re}\,\{(f_k(i\omega)I_0)^2e^{2i\omega t}/2i\omega\}+\tfrac{1}{2}\partial/\partial\sigma(f_kf_k^*)_{p=i\omega}I_0I_0^*]. \quad\ldots\ldots (32)$$

Thus

$$\mathscr{W}(t)=\tfrac{1}{2}I_0I_0^*(\partial R_0/\partial\sigma)_{p=i\omega}-\tfrac{1}{2}I_0I_0^*\sum_k R_k\partial/\partial\sigma(f_kf_k^*)_{p=i\omega}+\mathrm{Re}\,\{I_0^2(Z_0(i\omega)-\sum_k R_kf_k^2(i\omega))e^{2i\omega t}/2i\omega)\}.$$
$$\ldots\ldots\ldots\ldots (33)$$

The average energy storage $\overline{\mathscr{W}(t)}=W=T+V$ is found by averaging over a cycle $2\pi/\omega$ giving

$$W=\tfrac{1}{2}I_0I_0^*(\partial R_0/\partial\sigma)_{p=i\omega}-\tfrac{1}{2}I_0I_0^*\sum_k R_k\partial/\partial\sigma(f_kf_k^*)_{p=i\omega}. \quad\ldots\ldots\ldots (34)$$

Since the impedance $Z_0(p)$ is analytic, the Cauchy-Riemann equations may be used to write

$$(\partial R_0/\partial\sigma)_{p=i\omega}=(\partial X_0/\partial\omega)_{p=i\omega}. \quad\ldots\ldots\ldots\ldots (35)$$

Also

$$\partial/\partial\sigma(f_kf_k^*)_{p=i\omega}=2(\mathrm{Re}\,f_k)\partial/\partial\sigma(\mathrm{Re}\,f_k)+2(\mathrm{Im}\,f_k)\partial/\partial\sigma(\mathrm{Im}f_k). \quad\ldots\ldots\ldots (36)$$

But $f_k(p)$ is also analytic, so using the Cauchy-Riemann equations

$$\partial/\partial\sigma(f_kf_k^*)_{p=i\omega}=[2(\mathrm{Re}\,f_k)\partial/\partial\omega(\mathrm{Im}\,f_k)-2(\mathrm{Im}\,f_k)\partial/\partial\omega(\mathrm{Re}\,f_k)]_{p=i\omega} \quad\ldots\ldots\ldots (37)$$
$$=2[(\mathrm{Re}\,f_k(-p))\,\mathrm{Im}\,(\partial f_k(p)/\partial\omega)+(\mathrm{Im}\,f_k(-p))\,\mathrm{Re}\,(\partial f_k(p)/\partial\omega)]_{p=i\omega}. \quad\ldots (38)$$

Since $f_k(p)$ is a real function of p.

$$=2\,\mathrm{Im}\,(f_k(-p)\partial f_k(p)/\partial\omega)_{p=i\omega} \quad\ldots\ldots\ldots\ldots (39)$$
$$=2\,\mathrm{Re}\,(f_k(-p)f_k'(p))_{p=i\omega}. \quad\ldots\ldots\ldots\ldots (40)$$

Substitution of (35) and (40) into (34) gives

$$W = \tfrac{1}{2} I_0 I_0^* \partial X_0/\partial\omega - I_0 I_0^* \sum_k R_k \operatorname{Re}\,(f_k(-p) f_k'(p))_{p=i\omega}. \qquad (41)$$

The dissipation is more conveniently described by the real causal functions

$$F_k(p) = R_k^{\frac{1}{2}} f_k(p) \qquad (42)$$

so that (31) becomes

$$R_0(i\omega) = \sum_k F_k(i\omega) F_k^*(i\omega) = \sum_k F_k(-i\omega) F_k(i\omega) \qquad (43)$$

and the total average energy expression is

$$W = \tfrac{1}{2} I_0 I_0^* \partial X_0/\partial\omega - I_0 I_0^* \sum_k \operatorname{Re}\,(F_k(-p) F_k'(p))_{p=i\omega}. \qquad (44)$$

This equation may also be obtained from Goubau's version of Eq. (34) (Goubau, 1961) by a similar manipulation.

For loss-free systems the F_k, if any, are all identically zero, and Eq. (13) is recovered. Equations (44) and (43) also show, however, that if the resistive component of an impedance vanishes at some frequency (as for a minimum resistance impedance) the energy storage at that frequency is given uniquely by Eq. (13). Otherwise the energy storage depends upon the properties of the functions $F_k(p)$ describing the dissipation processes.

Similarly, by considering the one-port as an admittance

$$Y_0(p) = G_0(p) + iB_0(p) \qquad (45)$$

$$W = \tfrac{1}{2} V_0 V_0^* \partial B_0/\partial\omega - V_0 V_0^* \sum_k \operatorname{Re}\,(\Psi_k(-p)\Psi_k'(p))_{p=i\omega} \qquad (46)$$

where V_0 is the complex r.m.s. excitation voltage and

$$\Psi_k(p) = R_k^{-\frac{1}{2}} V_k(p)/V_0 \qquad (47)$$

are real causal transfer functions describing the dissipation. Clearly, the Ψ_k and F_k are related by

$$\Psi_k(p) = Y_0(p) F_k(p). \qquad (48)$$

Equations (44) and (46) are algebraically equivalent at all frequencies $p=i\omega$ except for poles or zeros of $Z_0(p)$, where the differentiations and substitutions are invalidated.

Finally, a scattering matrix version of (44) and (46) also exists which does not have the singular frequencies on the $p=i\omega$ axis. Let $S_0(p)$ be the scattering matrix (one-dimensional) of the impedance $Z_0(p)$. Further, let $S_{0k}(p)$ be elements of the scattering matrix $\mathbf{S}$ of the network as a whole where the o-port constitutes the given port $Z_0(p)$ and the k^{th}-port is terminated in the k^{th} resistor R_k. The $\mathbf{S}$ matrix is normalized to the resistances R_k terminating the ports. Two properties of $\mathbf{S}$ are important here. (i) Since $\mathbf{S}$ describes a loss-free system it is unitary. (ii) The elements of $\mathbf{S}$ are real analytic functions of p for $\operatorname{Re} p > 0$ (causal behaviour). A similar energy conservation argument to that used for deriving (44) gives

$$W = -a_0 a_0^* \operatorname{Im}\{S_0(-i\omega)\partial S_0(i\omega)/\partial\omega\} - a_0 a_0^* \operatorname{Re}\{\sum_k S_{0k}(-i\omega) S_{0k}'(i\omega)\} \qquad (49)$$

where $a_0 a_0^*$ is power incident on the one-port. In obtaining (49), the unitarity of $\mathbf{S}$ occupies an equivalent place to (31) or (43) in obtaining the impedance form (44). The scattering matrix form (49) for the energy storage is essentially the same as that derived rather differently and under more restricted conditions by Kishi and Nakazawa (1963). Notice that the present derivations of Eqs. (44), (46) and (49) are not restricted to circuits containing only reciprocal elements. Neither are they intrinsically restricted to lumped-element circuits since only general analytical properties of the immittance functions are used. However, for a continuum of dissipative processes the summations over the k resistors must be replaced by integrations over the volumes in which dissipation occurs.

The expressions (44), (46) and (49) for the energy storage, as expected, all involve some aspects of the internal structure of the one-port. The derivation has been a complementary one in which attention has been concentrated not on the mechanisms of energy storage, but on the mechanisms by which energy is not stored (i.e., dissipated). The results thus involve properties of the way in which energy is dissipated in the network as typified by the functions $F_k(p)$. Apart from general

transfer functions conditions and the overall loss condition (43), these functions are arbitrary and depend upon the exact realization of the one-port.

The three forms (44), (46) and (49) all have the same content except for the inappropriateness of (44) or (46) at poles or zeros respectively of $Z_0(p)$. Equation (49) is the most general in this sense since the scattering matrix formulation avoids these problems. However, in other ways the impedance or admittance forms are more closely related to conventional language and synthesis techniques for one-ports. Thus Eq. (44) will be regarded as the basic expression for further development, although with some modifications similar arguments could be based on (46) or (49).

One fact that is immediately apparent from (44) and (13) is that if $Z_0(p)$ is not a minimum reactance impedance (i.e., it has simple poles on the $p=i\omega$ axis) the energy storage is the same as that of two impedances excited by the same current, one impedance being the minimum reactance part of $Z_0(p)$ and the other a pure reactance corresponding to the non-minimum reactance part of $Z_0(p)$. The f_k and hence the F_k of the resulting minimum reactance impedance are the same as for the original $Z_0(p)$. Thus at our convenience we need consider only minimum reactance impedances, the energy storage for a non-minimum reactance impedance being obtained by the addition described above.

V. Application of the Vratsanos Theorem

Although the separate dissipation transfer functions F_k are not usually known, if $Z_0(p)$ is known as a function of the magnitudes of the separate resistors R_k in the network, Vratsanos' theorem (Vratsanos, 1957) may be used to determine the energy storage uniquely. This approach is limited further to reciprocal networks only, since Vratsanos' theorem is valid only for reciprocal networks.

Suppose $Z_0(p)$ is given as the functional form $Z_0(p,R_k)$, where the R_k are the actual magnitudes of all of the resistors in the network. Then Vratsanos' theorem states that

$$I_k^2/I_0^2=\partial Z_0/\partial R_k \qquad (50)$$

i.e.

$$f_k^2=\partial Z_0/\partial R_k \quad \text{from (21)} \qquad (51)$$

or

$$F_k^2=R_k\partial Z_0/\partial R_k \quad \text{from (42)} \qquad (52)$$

i.e.

$$F_k^2=(\partial Z_0/\partial \ln R_k) \qquad (53)$$

or if we introduce the sensitivity S_k of Z_0 with respect to R_k, i.e.

$$S_k=\frac{\partial \ln Z_0}{\partial \ln R_k}=\frac{R_k}{Z_0}\frac{\partial Z_0}{\partial R_k} \qquad (54)$$

$$F_k^2=Z_0S_k. \qquad (55)$$

Thus the F_k^2 may be determined from (52) or (53) and used to evaluate $\sum_k \mathrm{Re}\,(F_k(-i\omega)F_k'(i\omega))$ for substitution into Eq. (44) for the energy storage. I.e.

$$F_k(-i\omega)F_k'(i\omega)=\tfrac{1}{2}[(\partial Z_0(-i\omega)/\partial R_k)/(\partial Z_0(i\omega)/\partial R_k)]^{\frac{1}{2}}\partial^2 Z_0(i\omega)/\partial i\omega\partial \ln R_k. \qquad (56)$$

In principle only the dependence of $R_0(i\omega)$ on the R_k is essential. From (53)

$$\mathrm{Re}\,(F_k(i\omega))^2=\partial R_0(i\omega)/\partial \ln R_k \qquad (57)$$

and since $F_k(p)$ and hence $(F_k(p))^2$ is analytic and finite for $\mathrm{Re}\,(p)\geq 0$, the conjugate $\mathrm{Im}\,(F_k(i\omega))^2$ may be found from the Gewertz or Bode procedure (Balabanian, 1958, sec. 3.6) for rational functions, or by a Hilbert transform (Bode, 1945, Chap. XIV). Notice also that

$$\begin{aligned} R_0(i\omega)&=\sum_k F_k(-i\omega)F_k(i\omega)\\ &=\sum_k |\,\partial Z_0(i\omega)/\partial \ln R_k\,|. \end{aligned} \qquad (58)$$

VI. Energy Storage in Networks with One Resistance

A network containing a single resistance is the simplest case of a network which can represent a general impedance Z_0. Darlington synthesis (Balabanian, 1958) shows that any lumped-element impedance can be obtained from such a network. Apart from being a simple special case, this type of network occupies a central position in demonstrating that a minimum energy storage exists and that a minimum energy synthesis is possible.

Since the system contains only one resistance, the dissipation is described by a single $F_k(p)=F(p)$ and Eq. (43) is simply

$$R_0(i\omega)=F(-i\omega)F(i\omega)=F^*(i\omega)F(i\omega) \qquad (59)$$

and the energy storage (Eq. (44)) is

$$W=T+V=\tfrac{1}{2}I_0I_0^*\partial X_0/\partial\omega-I_0I_0^*\,\mathrm{Re}\,\{F(-i\omega)F'(i\omega)\} \qquad (60)$$

$$=\tfrac{1}{2}I_0I_0^*\partial X_0/\partial\omega-I_0I_0^*R_0\,\mathrm{Re}\,\{F'(i\omega)/F(i\omega)\}\ \text{using (59).} \qquad (61)$$

For a lumped element network $F(p)$ can always be written as a product of a unique minimum phase shift function $F_{\min}(p)$, having no zeros in $\mathrm{Re}\,p>0$ and satisfying Eq. (59), together with a non-minimum phase shift factor, i.e.

$$F(p)=F_{\min}(p)\prod_k\{(p-p_k)/(p+p_k)\}^{M_k} \qquad (62)$$

where M_k is the multiplicity of the zero of $F(p)$ at $p=p_k$ and

$$\mathrm{Re}\,p_k>0. \qquad (63)$$

Substitution of Eq. (62) in (61) gives

$$W=\tfrac{1}{2}I_0I_0^*\partial X_0/\partial\omega-I_0I_0^*R_0\,\mathrm{Re}\,\{F'_{\min}(i\omega)/F_{\min}(i\omega)\}+I_0I_0^*R_0\sum_k M_k\left\{\frac{p_k}{p_k^2+\omega^2}+\frac{p_k^*}{p_k^{*2}+\omega^2}\right\} \qquad (64)$$

$$=\tfrac{1}{2}I_0I_0^*\partial X_0/\partial\omega-I_0I_0^*\,\mathrm{Re}\,\{F_{\min}(-i\omega)F'_{\min}(i\omega)\}+2I_0I_0^*R_0\sum_k M_kp_k/(p_k^2+\omega^2) \qquad (65)$$

since complex values of p_k occur in conjugate pairs. But

$$\frac{p_k}{p_k^2+\omega^2}+\frac{p_k^*}{p_k^{*2}+\omega^2}=\frac{(p_k+p_k^*)(\omega^2+p_kp_k^*)}{(p_k^*p_k-\omega^2)^2+\omega^2(p_k+p_k^*)^2}>0$$

$$\text{since } \mathrm{Re}\,p_k>0, \qquad (66)$$

thus the contribution from non-minimum phase shift factors to the energy storage, namely

$$2I_0I_0^*R_0\sum_k M_kp_k/(p_k^2+\omega^2), \qquad (67)$$

is always positive. Physically, surplus non-minimum phase shift factors increase the group time delay for the transfer of energy to the energy dissipating resistance and so increase the energy storage (Kishi and Nakazawa, 1963).

Consequently,

$$W\geq\tfrac{1}{2}I_0I_0^*\partial X_0/\partial\omega-I_0I_0^*R_0\,\mathrm{Re}\,\{F'_{\min}(i\omega)/F_{\min}(i\omega)\} \qquad (68)$$

equality applying when $F(p)$ has no zeros in $\mathrm{Re}\,p>0$.

For the subsequent development, or for the situation in which R_0 is known only from measurements of Z_0 rather than analytically, another form of (68) may be obtained. At the same time this form indicates how the specialization to lumped-element networks might be relaxed.

From Eq. (59) and the fact that $F(p)$ is a real function of p

$$-\tfrac{1}{2}(\partial R_0/\partial\omega)/R_0=\mathrm{Im}\,\{F'(i\omega)/F(i\omega)\}. \qquad (69)$$

The contribution to the energy in Eq. (61), which involves the dissipation function $F(p)$, is proportional to $\mathrm{Re}\,\{F'(i\omega)/F(i\omega)\}$. Thus we require the real part of the function $G(i\omega)=F'(i\omega)/F(i\omega)$ whose imaginary part is known in terms of R_0 from (69). For $\mathrm{Re}\,p\geq0$, $F(p)$ is a real analytic function. Consequently so is

$$G(p)=F'(p)/F(p) \qquad (70)$$

except when $F(p)=0$. Moreover, if $F(p)$ has a zero of order M_k at $p=p_k$, $G(p)$ has a simple pole of residue M_k. Thus $G(p)$ is analytic in $\mathrm{Re}\, p \geq 0$ except for simple poles of residue M_k at zeros of $F(p)$. These poles can occur in complex conjugate pairs anywhere in $\mathrm{Re}\, p > 0$ as a result of non-minimum phase shift factors in $F(p)$, or on the $p=i\omega$ axis if $R_0(i\omega)$ vanishes.

Contour integration may now be used to relate the real and imaginary parts of $G(i\omega)$. The presence of poles of $G(p)$ in $\mathrm{Re}\, p \geq 0$ necessitates a slightly different treatment from the usual one (Bode, 1945, Chap. XIV). We suppose $G(p)$ regular at infinity with

$$\lim_{\omega \to \pm\infty} G(i\omega) = G_\infty. \qquad (71)$$

Since $G(p)$ is a real function of p, G_∞ is real.

Consider the contour integral

$$\int_\Gamma \frac{G(p)-G_\infty}{p-i\omega} \mathrm{d}p,$$

where Γ is basically a large semi-circular contour extending $-i\rho$ to $i\rho$ along the imaginary p axis and closed by an arc of radius ρ in the half-plane $\mathrm{Re}\, p > 0$. The contour is indented into $\mathrm{Re}\, p > 0$ by small semi-circles of radius ε at $p=i\omega$ and at any zeros, $p=i\omega_n$, of $F(p)$ on the imaginary p axis.

Then by Cauchy's theorem

$$\int_\Gamma \frac{G(p)-G_\infty}{p-i\omega} \mathrm{d}p = -2\pi i \{\text{sum of residues of } (G(p)-G_\infty)/(p-i\omega) \text{ inside } \Gamma\}. \qquad (72)$$

As $\rho \to \infty$ the contribution from the large semi-circle vanishes, and as $\varepsilon \to 0$ the small semi-circles contribute according to the residues s_n of $(G(p)-G_\infty)/(p-i\omega)$ at the points $p=i\omega_n$ and at $p=i\omega$. Equation (72) then becomes

$$\mathscr{P}\int_{-\infty}^{\infty} \frac{G(i\xi)-G_\infty}{\xi-\omega} \mathrm{d}\xi + i\pi\{G(i\omega)-G_\infty\} + \pi i \sum_n s_n(\omega) = -2\pi i \sum_k r_k(\omega) \qquad (73)$$

where $\mathscr{P}$ denotes the Cauchy principal value and $r_k(\omega)$ are residues of $G(p)/(p-i\omega)$ at poles of $G(p)$ in $\mathrm{Re}\, p > 0$. The imaginary part of Eq. (73) gives

$$\mathrm{Re}\; G(i\omega) = G_\infty - \frac{1}{\pi}\mathscr{P}\int_{-\infty}^{\infty} \frac{\mathrm{Im}\; G(i\xi)}{\xi-\omega} \mathrm{d}\xi - 2\sum_k \mathrm{Re}\; r_k(\omega) \qquad (74)$$

After using (69) and evaluating the residues, this becomes

$$\mathrm{Re}\;\{F'(i\omega)/F(i\omega)\} = G_\infty + \frac{1}{2\pi}\mathscr{P}\int_{-\infty}^{\infty} \frac{\partial R_0(i\xi)/\partial\xi}{R_0(i\xi)(\xi-\omega)} \mathrm{d}\xi - 2\sum_k \frac{M_k p_k}{p_k^2+\omega^2}. \qquad (75)$$

Thus from (61)

$$W = \tfrac{1}{2} I_0 I_0^* \partial X_0/\partial\omega - I_0 I_0^* R_0 \left\{ G_\infty + \frac{1}{2\pi}\mathscr{P}\int_{-\infty}^{\infty} \frac{\partial R_0(i\xi)/\partial\xi}{R_0(i\xi)(\xi-\omega)} \mathrm{d}\xi - 2\sum_k \frac{M_k p_k}{p_k^2+\omega^2} \right\}. \qquad (76)$$

For a finite lumped-element system G_∞ vanishes and (76) reduces to (65) with

$$\mathrm{Re}\;\{F_{\min}(-i\omega) F'_{\min}(i\omega)\} = \frac{R_0}{2\pi}\mathscr{P}\int_{-\infty}^{\infty} \frac{\partial R_0(i\xi)/\partial\xi}{R_0(i\xi)(\xi-\omega)} \mathrm{d}\xi. \qquad (77)$$

In distributed systems for which G_∞ need not vanish, the term in G_∞ has a simple physical interpretation. $(-G_\infty)$ is the time delay as $\omega \to \pm\infty$ and arises from a surplus exponential factor representing a constant time delay. Consequently G_∞ is always non-positive.

We conclude that

$$W \geq \tfrac{1}{2} I_0 I_0^* \partial X_0/\partial\omega - I_0 I_0^* R_0 \frac{1}{2\pi}\mathscr{P}\int_{-\infty}^{\infty} \frac{\partial R_0(i\xi)/\partial\xi}{R_0(i\xi)(\xi-\omega)} \mathrm{d}\xi \qquad (78)$$

or

$$W \geq \tfrac{1}{2} I_0 I_0^* \partial X_0/\partial\omega - I_0 I_0^* \;\mathrm{Re}\;\{F_{\min}(-i\omega) F'_{\min}(i\omega)\} \qquad (79)$$

equality holding when $F \equiv F_{\min}$, the dissipation function having no non-minimum phase factors of any kind. Thus to a prescribed one-resistor network there corresponds a minimum energy storage uniquely determined by (78) from the given impedance function.

If the network is a lumped-element network and R_0 is a known rational function, Eq. (79) can be used directly using standard algebraic methods for finding $F_{\min}$ rather than by evaluating the Hilbert transform in Eq. (78). Otherwise, in principle the Hilbert transform can be evaluated numerically from terminal measurements of R_0, but care is necessary in dealing with the principal value near singularities. Alternative forms for writing the transform (Bode, 1945 ; Morse and Feshbach, 1953) are then useful. For example

$$\frac{1}{\pi}\mathscr{P}\int_{-\infty}^{\infty}\frac{\partial R_0(i\xi)/\partial\xi}{R_0(i\xi)(\xi-\omega)}\mathrm{d}\xi=\frac{1}{\pi}\mathscr{P}\int_{-\infty}^{\infty}\frac{\{\partial\ln R_0(i\xi)/\partial\xi-[\partial\ln R_0(i\xi)/\partial\xi]_{\xi=\omega}\}}{\xi-\omega}\mathrm{d}\xi$$
$$=\frac{1}{\pi}\mathscr{P}\int_{-\infty}^{\infty}\frac{\partial/\partial\xi(\ln[R_0(i\xi)/R_0(i\omega)])}{\xi-\omega}\mathrm{d}\xi. \qquad (80)$$

The Hilbert transform form (78) for the minimum energy storage also occupies a central position in the subsequent theoretical development.

The above analysis, though not restricted to lumped-element networks, is limited to cases for which the assumption that $\lim_{\omega\to\pm\infty} G(i\omega)$ exists, is justified. The ordinary criteria for physical realizability do not exclude, for example, the possibility of an unbounded infinite set of zeros of R_0 and hence of $F(p)$ on the $p=i\omega$ axis. In such a case $\lim_{\omega\to\pm\infty} G(i\omega)$ does not exist. There is of course no difficulty with lumped-element systems and any distributed systems considered for extension of the results are assumed to be free of such complications.

VII. The Minimum Energy Storage of a General Network

In the previous section it was shown that for one-resistor networks there is a minimum energy storage, and an expression was derived for this minimum energy in terms of the terminal properties of the network as described by $Z_0(p)$. We now show that any network having the prescribed terminal behaviour irrespective of the number of resistors must store at least as much energy as this minimum for any particular $p=i\omega$.

A general network will contain N resistances R_k, the dissipation in each being described by the N functions F_k. The functions F_k are unknown in detail apart from the condition (43) on the total dissipation, i.e.

$$R_0(i\omega)=\sum_{k=1}^{N}|F_k(i\omega)|^2. \qquad (81)$$

Each $F_k(p)$ is a real causal function without poles for Re $(p)\geq 0$, so that $F_k(p)$ is determined by $|F_k(i\omega)|^2$ over the whole $p=i\omega$ axis except for non-minimum phase shift all-pass factors. Now suppose we write

$$R_0^{(k)}(i\omega)=|F_k(i\omega)|^2 \qquad (82)$$

so that $R_0^{(k)}$ is the contribution to the total terminal resistance R_0 from dissipation in the k^{th} resistor of the network. Since $R_0^{(k)}(i\omega)$ is always non-negative, there is associated with $R_0^{(k)}$ a minimum reactance impedance

$$Z_0^{(k)}(i\omega)=R_0^{(k)}(i\omega)+iX_0^{(k)}(i\omega). \qquad (83)$$

There is also a minimum reactance impedance $Z_0^{(\min)}$ associated with the total resistance R_0, and

$$Z_0^{(\min)}=\sum_{k=1}^{N}Z_0^{(k)} \qquad (84)$$
$$=\sum_{k=1}^{N}(R_0^{(k)}+iX_0^{(k)}). \qquad (85)$$

The prescribed impedance $Z_0(p)$ can differ from $Z_0^{(\min)}$ only by its non-minimum reactance component, i.e.

$$Z_0(i\omega)=iX(i\omega)+\sum_{k=1}^{N} Z_0^{(k)}(i\omega) \qquad (86)$$

where $iX(i\omega)$ is the non-minimum reactance function, if any, associated with Z_0. It has been seen in Section IV that the non-minimum reactance component of Z_0 presents no difficulties regarding energy storage, so we assume for simplicity in the current discussion that it has been subtracted out. That is, all of the impedances Z_0, $Z_0^{(k)}$ are minimum reactance. From (44) the energy storage is

$$W=\sum_{k=1}^{N}\left\{\tfrac{1}{2}I_0I_0^*\partial X_0^{(k)}/\partial\omega-I_0I_0^*\operatorname{Re}\,[F_k(-p)F_k'(p)]_{p=i\omega}\right\}. \qquad (87)$$

Thus from (60) the energy storage of the multi-resistor network realization is the same as the energy storage of N one-resistor networks having reactances $X_0^{(k)}$ and dissipation transfer functions F_k. We have already examined one-resistor networks in detail in the previous section. There is a minimum-energy storage $W_{\min}^{(k)}$ given by equation (78) for each of these networks. Thus

$$W\geq\sum_{k=1}^{N} W_{\min}^{(k)} \qquad (88)$$

the equality sign holding if every $F_k(p)$ has no zeros for $\operatorname{Re} p>0$. The magnitude of the sum in (87) will depend upon how the dissipation is distributed between the N resistors. We now consider another representation of Z_0 in which all dissipation takes place in a single resistor. From (78) the energy storage of this network exceeds

$$W_{\min}^{(0)}=\tfrac{1}{2}I_0I_0^*\partial X_0/\partial\omega-I_0I_0^*R_0\frac{1}{2\pi}\mathscr{P}\int_{-\infty}^{\infty}\frac{\partial R_0(i\xi)/\partial\xi}{R_0(i\xi)(\xi-\omega)}\mathrm{d}\xi \qquad (89)$$

unless $F(p)$ is minimum phase shift and equality applies. We now show that

$$\sum_{k=1}^{N} W_{\min}^{(k)}\geq W_{\min}^{(0)} \qquad (90)$$

so that from (88) the energy storage of any network realizing $Z_0(p)$ satisfies

$$W\geq\sum_{k=1}^{N} W_{\min}^{(k)}\geq W_{\min}^{(0)} \qquad (91)$$

Because

$$X_0(i\omega)=\sum_{k=1}^{N} X_0^{(k)}(i\omega) \qquad (92)$$

it is only necessary to show that

$$R_0(i\omega)\mathscr{P}\int_{-\infty}^{\infty}\frac{\partial R_0(i\xi)/\partial\xi}{R_0(i\xi)(\xi-\omega)}\mathrm{d}\xi\geq\sum_{k=1}^{N}R_0^{(k)}(i\omega)\mathscr{P}\int_{-\infty}^{\infty}\frac{\partial R_0^{(k)}(i\xi)/\partial\xi}{R_0^{(k)}(i\xi)(\xi-\omega)}\mathrm{d}\xi \qquad (93)$$

where

$$R_0^{(k)}(i\omega)\geq 0 \qquad (94)$$

and

$$R_0(i\omega)=\sum_{k=1}^{N} R_0^{(k)}(i\omega). \qquad (95)$$

Set

$$\eta_k(\omega)=R_0^{(k)}(i\omega)/R_0(i\omega). \qquad (96)$$

Then η_k denotes the fraction of the total power that is dissipated in the k^{th} resistor. I.e.

$$0\leq\eta_k(\omega)\leq 1. \qquad (97)$$

The η_k are not defined by (96) when $R_0=0$, which from (94), (95) implies $R_0^{(k)}=0$. η_k may be defined as a limit in the vicinity of $R_0=0$, but this is not necessary since the principal value reckoning of the integrals avoids such points. It is assumed, of course, that $\eta_k(\omega)\neq 0$, but $\eta_k(\omega)$ can still

have zeros when $R_0^{(k)}(i\omega)=0$ with $R_0(i\omega)\neq 0$. Because η_k is positive and indefinitely differentiable, its power expansion about a zero has an even power as the first non-vanishing term. This behaviour will be useful in dealing with the principal values of the integrals in (93) at $\eta_k=0$. Now consider

$$\mathscr{P}\sum_{k=1}^{N}\eta_k(\omega)\int_{-\infty}^{\infty}\left\{\frac{\partial R_0(i\xi)/\partial\xi}{R_0(i\xi)(\xi-\omega)}-\frac{\partial R_0^{(k)}(i\xi)/\partial\xi}{R_0^{(k)}(i\xi)(\xi-\omega)}\right\}\mathrm{d}\xi \quad \text{(98)}$$

$$=-\mathscr{P}\int_{-\infty}^{\infty}\sum_k\eta_k(\omega)(\partial\ln\eta_k(\xi)/\partial\xi)\frac{\mathrm{d}\xi}{\xi-\omega} \quad \text{(99)}$$

$$=-\mathscr{P}\int_{-\infty}^{\infty}[\partial\sum_k\{\eta_k(\omega)\ln[\eta_k(\xi)/\eta_k(\omega)]\}/\partial\xi]\frac{\mathrm{d}\xi}{\xi-\omega} \quad \text{(100)}$$

$$=\mathscr{P}\left\{\left[\frac{-\sum_k\eta_k(\omega)\ln\{\eta_k(\xi)/\eta_k(\omega)\}}{\xi-\omega}\right]_{-\infty}^{\infty}-\int_{-\infty}^{\infty}\frac{\sum_k\eta_k(\omega)(\ln\eta_k(\xi)-\ln\eta_k(\omega))}{(\xi-\omega)^2}\mathrm{d}\xi\right\}$$

from integrating by parts .. (101)

$$=-\mathscr{P}\int_{-\infty}^{\infty}\frac{\sum_k(\eta_k(\omega)\ln\eta_k(\xi)-\eta_k(\omega)\ln\eta_k(\omega))\mathrm{d}\xi}{(\xi-\omega)^2} \quad \text{(102)}$$

≥ 0 since the integrand in (102) is always ≤ 0 (see Appendix) .... (103)

The boundary terms from the integration by parts in (101) vanish because of the behaviour of η_k near zeros, and because of the factor $1/\eta_k(\omega)$ in the logarithm at $\xi=\omega$. The equality sign in (103) only holds when the integrand in (102) is identically zero, which requires (see Appendix)

$$\eta_k(\xi)\equiv\eta_k(\omega)=\text{constant}. \quad \text{(104)}$$

Equation (103) is equivalent to (93), so we have shown that (90) is generally true, the equality sign applying when the $\eta_k(\omega)$ are constants.

Thus, finally from (89), (90) and (91) it has been shown that for any specified minimum reactance impedance there exists a minimum energy storage $W_{\min}^{(0)}$, i.e.

$$W\geqq W_{\min}^{(0)} \quad \text{(105)}$$

with

$$W_{\min}^{(0)}=\tfrac{1}{2}I_0I_0^*\partial X_0/\partial\omega-I_0I_0^*R_0\left(\frac{1}{2\pi}\right)\mathscr{P}\int_{-\infty}^{\infty}\frac{\partial R_0(i\xi)/\partial\xi}{R_0(i\omega)(\xi-\omega)}\mathrm{d}\xi \quad \text{(106)}$$

$$=\tfrac{1}{2}I_0I_0^*\partial X_0/\partial\omega-I_0I_0^*\,\mathrm{Re}\{F_{\min}(-i\omega)F'_{\min}(i\omega)\} \quad \text{(107)}$$

where $F_{\min}(i\omega)$ is the minimum-phase shift function satisfying

$$F(-i\omega)F(i\omega)=R_0(i\omega).$$

Further, this minimum energy storage corresponds at all frequencies $p=i\omega$ to the energy storage of a minimum phase-shift Darlington synthesis of the impedance. Any non-minimum reactance component of the impedance $Z_0(p)$ can now be replaced in (106), (107) making them valid for a general impedance.

VIII. Realization of the Minimum Energy Storage

On general mathematical grounds the minimum energy storage was shown to correspond to that of a network with one-resistor in which the transfer function $F(p)$ is minimum phase shift (i.e., a minimum phase shift Darlington synthesis of $Z_0(p)$). It is well known that in conventional Darlington synthesis using reciprocal networks (Balabanian, 1958) minimum phase shift synthesis is not always possible, extra non-minimum phase shift factors in $F(p)$ being required to effect a synthesis. However, Hazony (1961) has shown that by using gyrators it is possible to carry out Darlington synthesis without surplus factors, so that minimum phase shift Darlington synthesis is possible. Thus the minimum energy storage for a lumped-element network corresponds to a realizable network. Thus the problem of a minimum energy synthesis of an impedance $Z_0(p)$ is

at once both posed and solved. Minimum energy synthesis will normally require non-reciprocal elements. It will certainly require non-reciprocal elements if for some $p=i\omega$

$$I_0 I_0^* \,|\, X_0/2\omega \,| > W_{\min}^{(0)} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (108)$$

since from (15) $I_0 I_0^* \,|\, X_0/2\omega \,|$ is the lower bound on the energy storage of a reciprocal network. This occurs in the simple example to be considered in the next section.

IX. A Simple Example

A simple example will illustrate a number of points without the complexities of elaborate realizations. Take $Z_0(p)=1+1/(p+1)$, and suppose a unit excitation current. By following the introductory steps to classical impedance synthesis the realization of Fig. 1 (*a*) is obtained. However, $Z_0(p)$ corresponds to an RC network function (Balabanian, 1958), so we know that the minimum energy storage for reciprocal networks is (Eq. (14))

$$W=|\,X_0\,|/2\omega=\tfrac{1}{2}/(1+\omega^2) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (109)$$

corresponding to Fig. 1 (*a*). Figure 1 (*b*) is an alternative synthesis with the same energy storage

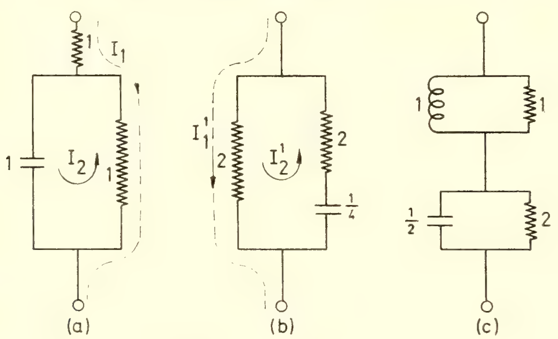

FIG. 1—Realizations of $Z_0(p)=1+1/(1+p)$.

Choosing mesh currents I_1 and I_2 in Fig. 1 (*a*) and I_1' and I_2' in Fig. 1 (*b*) gives mesh impedance matrices

$$\mathbf{Z} = \begin{pmatrix} 2, & -1 \\ -1, & 1+1/p \end{pmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (110)$$

$$\mathbf{Z}' = \begin{pmatrix} 2, & 2 \\ 2, & 4+4/p \end{pmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (111)$$

The two networks store the same energy and we see they are connected by a Cauer equivalence transformation (7) with

$$\mathbf{T} = \begin{pmatrix} 1 & 0 \\ 0 & -2 \end{pmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (112)$$

A simple example of a reciprocal network realization storing more energy than the minimum for reciprocal network is shown in Fig. 1 (*c*). This network is degenerate in the sense that the structure indicates two poles of $Z_0(p)$, but the choice of component values leads to only one in $Z_0(p)$. Such superfluous pole or zero behaviour is a characteristic of non-minimum energy reciprocal networks. This particular network stores three times the energy of the networks of Fig. 1 (*a*), 1 (*b*).

$Z_0(p)$ may also be realized by a reciprocal non-minimum phase shift Darlington synthesis (Fig. 2 (*a*)), for which

$$F(p)=(\sqrt{2}-p)/(1+p). \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (113)$$

It cannot be realized by a minimum phase shift synthesis using reciprocal elements alone. The energy storage of this realization is found from Eq. (60) to be

$$W=\tfrac{1}{2}(3+2\sqrt{2})/(1+\omega^2) \quad \ldots\ldots (114)$$

$$=(3+2\sqrt{2})\,|\,X_0/2\omega\,| \quad \ldots\ldots (115)$$

which is $(3+2\sqrt{2})$ times that of the minimum-energy storing reciprocal networks. It must of course exceed the minimum for reciprocal networks because there is magnetic as well as electric energy storage.

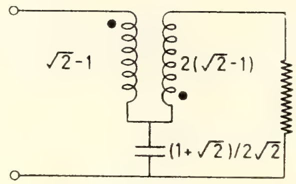

FIG. 2—Darlington reciprocal network synthesis of $Z_0(p)=1+1/(1+p)$.

We now consider what is the minimum possible energy storage for any realization of $Z_0(p)$. This may be evaluated either by (106) or more conveniently by (107). The minimum phase shift $F(p)$ for this impedance is

$$F_{\min}(p)=(\sqrt{2}+p)/(1+p). \quad \ldots\ldots (116)$$

The non-minimum phase shift function (113) differs from this by the all pass factor $(\sqrt{2}-p)/(\sqrt{2}+p)$. The minimum possible energy storage is then

$$T+V=\tfrac{1}{2}(3-2\sqrt{2})/(1+\omega^2)=(3-2\sqrt{2})\,|\,X_0/2\omega\,|. \quad \ldots\ldots (117)$$

Thus the minimum energy is only $(3-2\sqrt{2})\approx 0{\cdot}17$ of the minimum reciprocal network energy storage. We note also that (115) exceeds (117) by

$$2\sqrt{2}/(1+\omega^2)=2R_0.\{\sqrt{2}/(\omega^2+2)\}. \quad \ldots\ldots (118)$$

This excess is the non-minimum phase shift contribution (Eq. (65)) from the zero of $F(p)$ at $p=\sqrt{2}$. All that remains is to show how to achieve a synthesis with this minimum energy. Hazony (1961) has considered examples of non-reciprocal Darlington synthesis without surplus factors. His methods give the syntheses shown in Fig. 3 (*a*), (*b*).

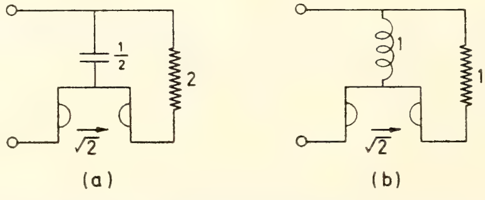

FIG. 3—Non-reciprocal Darlington syntheses of $Z_0(p)=1+1/(1+p)$.

These syntheses are independent of the sign of the gyrator coupling. One sign, as in Fig. 3 with Carlin's convention (Carlin, 1955), gives minimum phase shift networks corresponding to the $F(p)$ of Eq. (116), while the other gives $F(p)$ corresponding to (113). Notice also that both networks in Fig. 3 (with appropriate gyrator coupling signs) store the same energy and represent the same impedance, but in one it is entirely electric and in the other it is entirely magnetic. (This behaviour is peculiar to non-reciprocal networks (Smith, 1967).)

To illustrate the use of Vratsanos' theorem in evaluating the energy storage by this impedance, we must suppose $Z_0(p)$ is given as a function of the magnitudes of all resistors in the network and that the network is composed of reciprocal elements. For example, take the case where there are two resistors and

$$Z_0(p,R_k)=\frac{pR_1}{R_1+p}+\frac{2}{p+1/R_2}\;. \qquad (119)$$

Then

$$Z_0(p,R_k)=1+1/(1+p) \text{ when } R_1=1 \text{ and } R_2=1.$$

From (52)

$$F_1^2(p)=R_1(\partial Z_0/\partial R_1)_{R_1,R_2=1}=p^2/(1+p)^2 \qquad (120)$$

and

$$F_2^2(p)=2/(1+p)^2. \qquad (121)$$

The energy storage can then be evaluated to obtain

$$T+V=\frac{3}{2}/(1+\omega^2) \qquad (122)$$

which is the same as for the network of Fig. 1 (c).

X. Summary and Discussion

The average energy storage of a sinusoidally excited, general linear, passive network has been seen to be not determined by terminal behaviour alone. That is, equivalent circuits in the usual terminology do not store the same energy for the same excitation. However, the class of networks related by Cauer's equivalence transformation do.

The energy storage is uniquely determined by the terminal behaviour whenever the system dissipates no energy, is an RL or RC network, or when the dependence of the terminal behaviour on the individual dissipative processes is known.

For reciprocal element networks a simple lower bound exists for the energy storage at each frequency. This bound is attained at all frequencies by RL or RC networks.

A general expression for the energy storage has been found and used to show that for any linear, passive network there is a minimum possible energy storage corresponding to a prescribed impedance. Further, this bound is attainable at all frequencies as a minimum energy synthesis. The minimum energy synthesis is a minimum phase-shift Darlington synthesis, and normally non-reciprocal elements (gyrators) are required for its realization.

Only sinusoidal excitation of the impedance has been considered in detail. If we consider excitation represented by a Fourier integral, Parseval's formula can be used to find the time integral of the instantaneous stored energy since the storage in every element is a quadratic function of the voltage or current. The time integral of the energy storage is the integral over all frequencies of the energy storage associated with the individual Fourier components of the excitation. Consequently the network storing minimum energy (in the sense of an integration over time) is the minimum energy synthesis of the impedance. Instantaneous energy storage as a function of time would need to be approached by energy conservation arguments analogous to Section IV, but involving the time-domain behaviour of the dissipation functions.

The methods used in the development are not intrinsically restricted to lumped-element systems, so that with perhaps some qualifications the results should extend to distributed systems with non-rational $Z_0(p)$. Also, the results are not restricted to electrical impedances, for example, the same arguments apply for an acoustic impedance. An extension to multi-port systems may also be possible. That non-reciprocal elements may sometimes be necessary for the general case to attain the minimum energy can be expected intuitively from relationships between group time-delay and energy storage (Kishi and Nakazawa, 1963). Carlin (1967) considers time-delays in a matched loss-free two-port and shows that negative group time delays are possible, but only in non-reciprocal systems.

There are still some further questions of interest. Is there a synthesis of a general RLC network which attains the reciprocal network minimum energy bound $\frac{1}{2}I_0I_0^*\left|\frac{X_0}{\omega}\right|$ at all frequencies?

This is easily shown to be impossible in general, by the counter example of a unit inductor in series with a parallel combination of a unit resistor and unit capacitor. $Z_0=(p^2+p+1)/(p+1)$. This network is a minimum energy network, and for unit current stores a non-zero amount of energy at $\omega=0$. But $\frac{1}{2}|X_0/\omega|=0$ at $\omega=0$, which is less than the minimum possible energy. Thus the bound $\frac{1}{2}I_0I_0^* \left|\frac{X_0}{\omega}\right|$ for reciprocal networks is not a close one and the absolute minimum can exceed it. Perhaps there is a better bound for the energy storage in reciprocal networks. If so, is it attainable at all frequencies by some realization ? That is, is there a minimum energy reciprocal element synthesis in the same way as there is an overall minimum energy synthesis ? Classical methods of synthesis have stressed the number or types of elements required for synthesis. We could ask whether Brune synthesis, for example, occupies a special place in the energy storage hierarchy.

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XII. Appendix

The following inequality is proved :

If $$f=\sum_{i=1}^{N}(p_i \ln q_i - p_i \ln p_i) \quad \ldots \text{(A1)}$$

with $$\sum_{i=1}^{N} p_i=1,\ \ p_i>0 \quad \ldots\ldots \text{(A2)}$$

and $$\sum_{i=1}^{N} q_i=1,\ \ q_i>0 \quad \ldots\ldots \text{(A3)}$$

then $$f\leq 0 \quad \ldots\ldots\ldots\ldots \text{(A4)}$$

the equality sign implying
$$p_i=q_i,\ i=1,\ N \quad \ldots\ldots \text{(A5)}$$

Write f as
$$f=\sum_{i=1}^{N} p_i\left(\ln\frac{q_i}{p_i}+1-\frac{q_i}{p_i}\right) \quad \ldots \text{(A6)}$$

which is equivalent to (A1) by virtu of (A2) and (A3).

Now $\ln x+1-x<0$ for all $x>0$ except $x=1$ when $\ln x+1-x=0$. Consequently, from (A6) $f<0$ unless all $p_i=q_i$, in which case $f=0$.

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